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A preliminary interpretation of Tellus airborne magnetic and electromagnetic data for Northern Ireland

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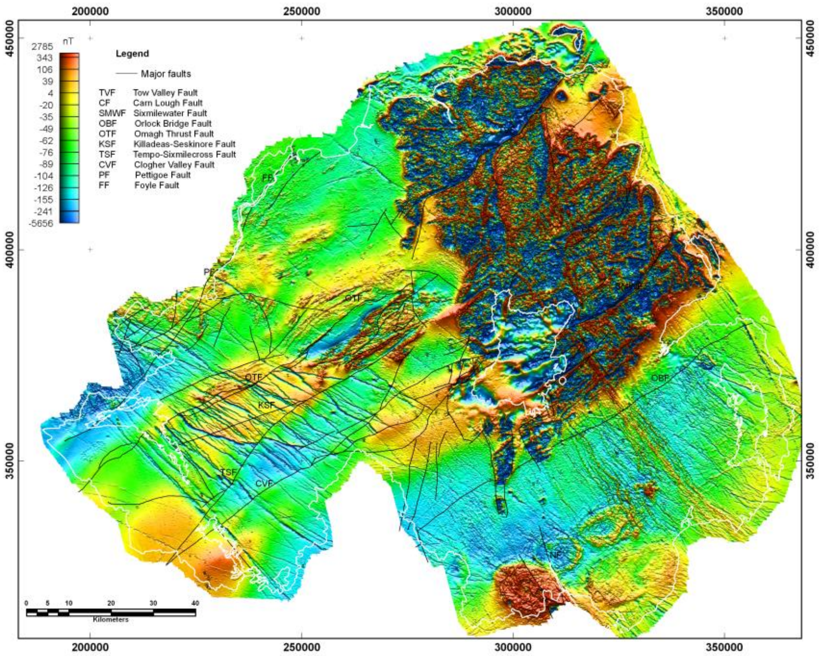
Internal Report IR/07/041



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A preliminary interpretation of Tellus airborne magnetic and electromagnetic data for Northern Ireland

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Keywords

Airborne survey, magnetic, electromagnetic, minerals, Northern Ireland.

Front cover

Colour shaded relief Total Magnetic Intensity map of Northern Ireland.

Bibliographical reference

B C CHACKSFIELD. 2010. A preliminary interpretation of Tellus airborne magnetic and electromagnetic data for Northern Ireland. *British Geological Survey Internal Report*, IR/07/041. 51pp.

Keyworth, Nottingham British Geological Survey 2010

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Acknowledgements

This report would not have been possible without the efforts of the Tellus project team and all those in BGS and the Geological Survey of Finland who were part of the Joint Airborne Capability. They were responsible for the acquisition and processing of the airborne data that are presented here. I am also grateful to Paul Turner and Geoff Kimbell of BGS for their advice and assistance with the project GIS.

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Summary

An airborne geophysical survey of the whole of Northern Ireland was flown in 2005 and 2006 as part of the Tellus project. This project was funded by the Northern Ireland Department of Enterprise Trade and Investment and by the Rural Development Programme through the Northern Ireland Programme for Building Sustainable Prosperity (www.tellus.detini.gov.uk). The aircraft used was a De Havilland Twin Otter which carried magnetic, electromagnetic and radiometric sensors. It was operated as a joint venture between the British Geological Survey (BGS) and the Geological Survey of Finland (GTK). Survey lines were spaced 200 m apart and orientated NNW or ESE (165 and 345º). The flying height was 56 m above ground (185') in rural areas rising to 240 m over urban areas. This report presents a preliminary interpretation of the airborne magnetic and electromagnetic data and shows examples of the types of geological feature that can be identified from the data on a regional scale. A few comments on the radiometric results are also included together with a brief evaluation of the mineral potential of Northern Ireland based on the airborne geophysical data. For the preliminary interpretation many high resolution images of the magnetic, electromagnetic and radiometric data were generated and analysed in a GIS system along with existing regional gravity, digital geological mapping and mineral occurrences data. The main structural elements were identified and digitised and a structure map produced.

The Tellus data have provided a wealth of new information about the geology, regional structure and mineral potential of Northern Ireland and the GIS has proven a powerful tool for analysing these data at both regional and local scales. The strong magnetic signature of the Antrim basalts allows their surface extent to be mapped accurately in areas of poor exposure, and within the basalt outcrop lineaments associated with bounding faults of sedimentary basins have been identified. The margins of the Tyrone Igneous Complex and the internal structure of the complex itself are revealed in stunning detail and many new faults and sheared rocks identified. Within the adjacent Dalradian rocks arcuate linear magnetic anomalies related to fold structures and several important magnetic marker horizons have been revealed. The full extent of the dyke swarms that cross Northern Ireland has only now come to light with the new Tellus magnetic data. Dykes reveal regional stress fields, and those that are offset can be used to measure post Palaeogene fault displacements. The margins of the major intrusive centres of the Newry Igneous Complex, Mourne Mountains, Slieve Gullion and Carlingford and their internal structure have also been delineated by the magnetic and gravity data.

The rocks that make up Northern Ireland show a considerable variation in their electrical properties and where contrasts between geological formations are sufficiently large their geological distribution can be mapped.

The main mineral prospectivity target in Northern Ireland lies within the area covering the Upper Dalradian rocks of the Sperrins area, the Omagh Thrust Fault and the sheared rocks of the Tyrone Igneous Complex where this area shows the greatest degree of shearing and faulting. Magnetic anomalies depict a series of arcuate structures within which mineralisaton is located in a series of distinct belts and appears to be spatially related to shearing and faulting. A prospectivity study of this area is highly recommended.

1 Introduction

An airborne geophysical survey of the whole of Northern Ireland was flown in 2005 and 2006 as part of the Tellus project. This project was funded by the Northern Ireland Department of Enterprise Trade and Investment and by the Rural Development Programme through the Northern Ireland Programme for Building Sustainable Prosperity (www.tellus.detini.gov.uk). The aircraft used was a De Havilland Twin Otter which carried magnetic, electromagnetic and radiometric sensors. It was operated as a joint venture between the British Geological Survey (BGS) and the Geological Survey of Finland (GTK). Survey lines were spaced 200 m apart and orientated NNW or ESE (165 and 345º). The flying height was 56 m above ground (185') in rural areas rising to 240 m over urban areas and as necessary to safely clear obstacles. Further details of the survey specification are documented in the final processing report (Beamish et al., 2007).

This report presents a preliminary interpretation of the Tellus airborne magnetic and electromagnetic data and shows examples of the types of geological feature that can be identified from the data on a regional scale. A brief evaluation of the mineral potential of Northern Ireland based on the airborne geophysical data is also included.

The radiometric data have been interpreted separately by Jones (2007), although a few radiometric images have been included in this report to show the relationship between the radiometric, magnetic and electromagnetic data.

The interpretation of the Tellus magnetic and electromagnetic data was carried out in a GIS environment using ArcGIS version 9. Tellus data were integrated with legacy gravity and magnetic data and geological data derived from the published 1:250 000 geological map of Northern Ireland. A digital terrain model derived from the Tellus data was also used. Numerous geo-registered images were produced together with contour maps and point data showing mineral occurrences to help evaluate the mineral potential. From this exercise the main structural domains, lineaments, faults, igneous intrusions and dykes were digitised and a structural overview map produced.

2 Background

2.1 PREVIOUS INTERPRETATION

Prior to the new Tellus airborne survey interpretation the most comprehensive and thorough regional interpretation of the gravity and aeromagnetic data for Northern Ireland was carried out by Carruthers, et. al. (1997). This work included the production of a suite of images derived from digital gridded gravity and magnetic data compilations and included some geophysical profile modelling. The most important results from this work were incorporated into the Geophysics and Concealed Geology Chapter (Chapter 19) of the regional guide "The Geology of Northern Ireland: Our Natural Foundation" (Mitchell, 2004).

The gravity data proved particularly useful in showing the major regional crustal structures and as such a new set of geo-referenced images of the gravity data were generated for the present study (Figures 2 and 3), to aid interpretation of the new Tellus airborne geophysical data. The gravity data grids were expanded to include data for mainland UK re-projected onto the Irish National Grid. Likewise, images of the old magnetic data were re-generated for comparison with the Tellus data (Figure 4) and similarly expanded to include data for northern Britain to view the Tellus magnetic data within a wider regional context.

2.2 LEGACY GRAVITY AND MAGNETIC DATA

The main land regional gravity surveys were carried out by BGS between 1959 and 1960. Subsequently a lake bottom gravity survey of Lough Neagh was surveyed in 1984 using an underwater gravity meter, and an 'infill' survey over north County Antrim was undertaken in 1990. Additional data for adjacent and offshore areas was provided by the Dublin Institute for Advanced Studies, the UK Hydrographic Office and Western Geophysical. The land gravity data coverage for Northern Ireland is roughly 1 station per 1.25 square km. The data were gridded at 0.5km and subsequently re- interpolated onto a 200m grid cell size for high resolution plotting purposes. The old regional aeromagnetic survey was flown in 1959 by Canadian Aerosurveys at an altitude of 305m with north – south flight lines 2km apart and east-west tie lines at 10km intervals. Magnetic data were interpolated directly onto a 200m grid cell size.

3 Interpretation procedure

3.1 DATA PREPARATION

3.1.1 Gridding and filtering

Data processing, gridding, filtering and image generation were carried out using Geosoft Oasis Montaj Version 6.1 software. The Tellus airborne geophysical survey data were pre-processed in Geosoft prior to the interpretation stage and a series of primary grids were generated on the Irish National Grid projection from a set of cleaned and filtered Geosoft databases. Geosoft filters were then applied to the primary grids to smooth the data where necessary and to produce various derivative maps. The legacy gravity and magnetic data grids were converted from BGS 'in-house' USGS grid format to Geosoft GRD grid format and subsequently re-projected from UTM grid zone 30 (Central Meridian 3deg west) to the Irish National Grid co-ordinate system. The grids included various derivative grids generated from BGS Unix based in-house software. The Tellus airborne geophysical data were at a 50m grid cell size. Legacy gravity and magnetic data were at a cell size of 200m.

3.1.2 Geophysical image generation

For the Tellus project a series of high resolution regional images of the magnetic, electromagnetic and radiometric data were produced covering the whole of Northern Ireland. Additional legacy regional magnetic and gravity images were also produced as appropriate. All images were geo-referenced and put into a GIS system for interpretation.

Geophysical images of the magnetic and electromagnetic data were generated as colour shaded relief images using a modified equal area colour scale whereby each equal area colour scale was adjusted interactively to provide more colours covering the middle part of the data range and to remove oversaturated red and blue colours at the top and bottom ends of the colour scale. The Geosoft colour scales used for the shaded relief images were a combination of a 'wet look' hue, saturation and value (HSV) 256 colour scale and a modified equivalent 256 grey shade scale.

The combined effect produced a brighter colour image and a higher level of detail in the shading than the default Geosoft RGB colour and grey scales.

The radiometric images were generated as flat RGB colour images. The Total Count and single element Uranium, Thorium and Potassium images used a 256 red, green, blue (RGB) colour scale adjusted in the same way as the shaded relief colour scale to provide colour breaks at meaningful geological boundaries. The Ternary map used a colour combination of K=red, U=blue and Th=green.

The colour images were exported from Geosoft as geo-registered tiffs at a 50m cell size and then imported into a GIS system. In addition to the colour tiffs gravity and magnetic contours were generated using EarthVision software and contours were smoothed and tuned to suppress contours where gradients were steep. The contours are extremely effective in showing the relationship between for example gravity and magnetic anomalies when the gravity contours are overlain on the magnetic images. Contours have been omitted from the Figures in this report for clarity but are suitable for viewing and printing at scales between 1:250 000 and 1:50 000.

3.1.3 List of geophysical images produced

<u>Tellus Airborne survey</u>

Magnetic data:

Colour shaded relief   Total Magnetic Intensity
Reduced to Pole
Horizontal gradient
Analytic signal
Tilt derivative
First vertical derivative
Second vertical derivative
Pseudogravity field
Pseudogravity horizontal gradient

Electromagnetic data:

Colour shaded relief   Conductivity For high and low frequencies
Apparent Resistivity

Radiometric data:

Flat colour images   Ternary image

Total Count

U, Th ,K

Legacy gravity and magnetic data – colour shaded relief.

Regional aeromagnetic data:

Total Magnetic Intensity

Reduced to Pole

Horizontal gradient

Regional gravity data:

Bouguer gravity variable density

Residual Bouguer gravity with 5^{th} order polynomial removed

Residual of Bouguer gravity upward continued to 500m

Horizontal gradient of gravity field upward continued to 500m

3.1.4 Types of gravity and magnetic images used in the interpretation

Gravity maps Regional gravity anomaly maps are shown as variable density Bouguer anomaly onshore and free air anomaly offshore. The gravity map in this report has had a 5^{th} order polynomial surface removed from the data to enhance anomalies associated with sources at mid crustal to near surface levels.

Magnetic Maps Magnetic maps are shown as Total Magnetic Intensity and Reduced to Pole anomaly. The latter is the Total Field anomaly converted to the field that would be observed at the magnetic pole (vertical field). This has the advantage of simplifying the anomaly pattern and adjusting the location of the peak anomaly to lie immediately over the source. However, if remanent magnetisation is present some distortion will occur.

Upward continuation**:** The primary gravity and magnetic gridded data have been further processed to enhance geophysical anomalies associated with near surface rocks and separate these from those associated with deeper sources. This process can be achieved by the method of upward-continuation. This process transforms the observed field to the field that would appear at some greater height. As the height increases so the response from narrow and shallow bodies diminishes, thus clarifying the response from deeper bodies and structure.

Residual anomaly**:** By subtracting the upward continued field from the observed field a series of residual anomaly maps can be produced. These can be considered as “depth slices”, and reflect the presence of bodies and structures, progressively deeper into the ground.

Vertical derivatives: The vertical gradient enhances the high frequencies at the expense of the low ones. This improves the resolution of near surface features, particularly where anomalies from adjacent bodies or bodies at different depths are overlapping.

Horizontal gradient**:** This enhances the response from near surface features and produces anomaly peaks along the edges of wide bodies.

Pseudogravity**:** The pseudogravity transform converts a total field anomaly into the gravity anomaly that would be observed over the same source if there was a one-to-one relationship between magnetisation and density. Both pseudogravity and reduction-to-pole centre anomalies over sources, but the pseudogravity emphasises longer wavelength features. The horizontal gradient of pseudogravity is useful for delineating the edges of deep-seated magnetic structures.

Analytic signal: This may be considered as a total gradient as it is effectively the vector sum of all the horizontal and vertical first derivatives. For narrow bodies peaks are always over the centre of the body.

3.2 GEOPHYSICAL IMAGE ANALYSIS

Images were analysed in ArcGIS and the main structural elements were identified and digitised on screen from the most informative images. The magnetic images showed an overwhelming amount of detail so features were digitised in separate shape files so that each structural component could be overlain separately on the images themselves or combined and colour coded to produce a structural overlay map. The main features digitised were as follows:

Magnetic data

- The surface outcrop of the Antrim Basalt,
- Lineaments associated with structures within the Antrim Basalt
- Lineaments related to faults and shear zones.
- Lineaments attributed to dyke swarms
- Margins of major intrusions
- Lineaments within and radiating from major intrusions.
- Lineaments related to fold structures.
- Major anomaly offsets
- Postulated terrane boundaries

Electromagnetic data

- Principal EM conductors
- Anomaly offsets

Gravity data

- Gravity lineaments attributed to faults
- Margins of igneous intrusions
- Deep seated faults

From the magnetic data the outcrop of the Antrim basalt was digitised mainly from the first vertical derivative of the magnetic field and the pseudogravity horizontal gradient field. The latter was used to delineate the internal structure within the basalt.

Faults, shear zones and fold belts were identified mainly from the horizontal gradient of the pseudogravity field. The pseudogravity field itself effectively suppressed the short wavelength anomalies due to the igneous dykes to reveal anomalies related to deeper structural features.

The margins and internal structure of the magnetic intrusions in County Down were interpreted from the pseudogravity horizontal gradient whilst the dyke swarms were identified using a combination of the reduced-to-pole field and the first vertical derivative image which was particularly effective in showing dyke swarms associated with the main intrusions.

The main EM conductors associated with fault structures and conductive pelite horizons were digitised from the conductivity image. The main geological divisions and resistive and conductive units and bounding faults were identified from the apparent resistivity map.

Regional magnetic and gravity data were used to identify the major deeper crustal faulting by zooming out to a wider area. The gradients depicting the margins of the major intrusions, sedimentary basins and geological units were digitised from the horizontal gradient maps. Postulated terrain boundaries and deep crustal lineaments were also digitised from these maps in conjunction with the pseudogravity map.

4 Geological interpretation.

4.1 MAGNETIC DOMAINS

Several magnetic domains have been identified from the new magnetic data and these have been numbered on the images and magnetic structure map (Figures 5-10). The domains consist of areas of high amplitude short wavelength anomalies caused by magnetic rocks that are exposed or lie near the surface and broader anomalies of a more regional nature indicative of magnetic bodies at a greater depth.

4.1.1 Basalt lavas of the Antrim Plateau

Magnetic anomalies associated with the Antrim basalt dominate the aeromagnetic map. Their strong magnetic signature allows the surface extent of the Antrim basalts to be mapped accurately in areas of poor exposure. Nearly all of the magnetic anomalies over the basalt outcrop are short wavelength high amplitude negative anomalies (coloured blue) that result from a strong natural remanent magnetisation component (NRM) that was acquired when the lavas cooled in a magnetic field that was in the opposite direction to the Earth's present day magnetic field. Palaeomagnetic studies (Reay, 2004) have shown that the stable bulk magnetisation of the basalt lava has a declination of about 190 degrees and an inclination of -60 degrees.

The margins of the basalt show a characteristic positive anomaly signature on the reduced to pole map (Figure 6) which is enhanced on the pseudogravity horizontal gradient and vertical derivative maps (Figures 8 and 9) as strong positive linear anomalies (red colour). The margins of distinct magnetic units within the basalt outcrop are similarly bounded by positive anomalies and these have been digitised as a series of lineaments that are thought to represent the margins of distinct structural blocks separated by faulting.

Although magnetic anomalies associated with the lavas are negative there are some areas that have a local positive signature. These are more readily seen on the pseudogravity field which has effectively suppressed but not entirely removed the short wavelength anomalies due to the basalt and enhanced the more regional magnetic component which appears to have a positive component more characteristic of the magnetic anomalies associated with the Midland Valley of Scotland. The pseudogravity map when viewed in conjunction with the reduced-to-pole map thus provides a window that enables the crustal structure beneath the basalt to be seen.

Interpretation of the magnetic data to determine which anomalies are caused by the basalt lavas and which are due to basement rocks is complex and requires further studies. Palaeomagnetic data have shown that the ratio between induced and remanent magnetisation (Koningsberger ratio Q) in the Antrim lavas may be close to 1 which implies that the magnetic anomalies may arise from variations in the magnetisation of the lava (mainly negative), variations in the shape and thickness of the lava pile, and the magnetic signature of the basement rocks which are generally positive.

Mainly negative magnetic anomalies occur in the north of County Antrim in area 1a (Figure 6) accompanied by a few ill-defined areas of local positive anomalies suggesting some variation in magnetic properties of the lavas which in the main are reversely magnetised. The negative anomalies in area 1a are terminated by the Tow Valley Fault which has a strong magnetic gradient associated with it.

Between the Tow Valley and Carnlough faults however three distinct magnetic blocks are present on the pseudogravity map (Figure 7, area 1b). These are coincident with gravity highs (figure 2) and mark a stepped change from negative anomalies to predominantly regional positive anomalies towards the northeast. The magnetic blocks are bounded by strong north south linear gradients that are coincident with pronounced gravity gradients. The gravity gradients are associated with the faulted margins of the Kilrea-Maghera and Loughguile sedimentary basins. Here low density Carboniferous, Triassic and Cretaceous rocks rest upon higher density Dalradian rocks of the Highland Border Ridge and give rise to a series of gravity troughs within a pronounced gravity high. The abrupt change to predominantly positive magnetic anomalies is therefore probably the result of thinning of the basalt across a series of fault bounded blocks that make up the Highland Border Ridge. Over the Dalradian sequence of northeast County Antrim where basalts are absent there remains a smooth regional magnetic high. The source of this anomaly is probably caused by the presence of magnetic rocks within the basement that underlies the Dalradian.

Much of the area that lies between the Carnlough Fault and the Sixmilewater Fault shows regions of both positive and negative magnetic anomalies on the pseudogravity image and is accompanied by an intermediate regional ‘background’ gravity anomaly. Area 1c to the south of the Carnlough Fault is characterised by mainly negative magnetic anomalies whereas area 1d is generally more positive and shows a pronounced magnetic high associated with an outcrop of rhyolites whose magnetisation component is predominantly induced.

The magnetic data indicates that the north trending Ballytober fault near Larne, that joins the Sixmilewater Fault, is an important deep crustal fault at the margin of the Larne sedimentary basin. To the east of the fault the pseudogravity map shows a high beneath the basin coincident with the gravity low over the lower density sedimentary basin fill. Magnetic data suggests the basalt lavas are very thin and die out to the east and that the positive pseudogravity anomaly is due to magnetic basement rocks beneath the basin that may or may not be the same as the basement underlying the Dalradian in area 1b.

In the Loch Neagh region (area 1e) the magnetic anomaly pattern is suppressed but clearly shows the intermittent presence of basalt lavas under Lough Neagh at shallow depths beneath non magnetic Quaternary sediments of the Loch Neagh Group. The Loch Neagh sedimentary basin is clearly defined by a gravity low (Figure 2) but the low also extends further north over the upper basalt formation which also has a relatively low density. There is a notable absence of basalt in the southwest corner of Loch Neagh where the anomaly pattern is predominantly positive and relatively smooth by comparison.

Magnetic anomalies beneath Loch Neagh are locally displaced by at least two northeast-trending linear gradients marked by positive anomalies on the reduced to pole map. These are accompanied by pronounced gravity gradients and probably represent the continuation of the two large faults mapped in the Crumlin area which displace the Loch Neagh Group and basalt outcrop. The Sixmilewater Fault does not have an obvious magnetic expression beneath Lough Neagh but it does have a strong gravity gradient (Figure 3) and appears to continue beneath Lough Neagh emerging to the west of the Loch as the Elagh Fault.

South of the Sixmilewater Fault anomalies over the basalt outcrop are negative and these change to more positive anomalies on the pseudogravity map along the basalt margin to the south and east. This is attributed to effects related to changes in basalt thickness possibly combined with the emergence of positive magnetic anomalies attributed to basement rocks.

In this region there are several northeast-trending lineaments with a Caledonian trend which are interpreted as fault displacements. These are cross cut by northwest lineaments associated with Palaeogene dykes that are broad positive anomalies. One of these appears to be a continuation of the positive anomaly relating to the main dyke swarm in the southeast part of Northern Ireland. This feature continues as far as the Sixmilewater Fault where it may be offset sinistrally by the fault and reappears as a linear positive anomaly beneath Loch Neagh and thereafter possibly continuing as far north as the Carnlough Fault.

4.1.2 Tyrone Igneous Complex

The second most prominent area of short wavelength magnetic anomalies shown as high relief on the magnetic maps is associated with basement rocks of the Midland Valley Terrane within the Central Inlier and Tyrone Igneous Complex (domain 2). The faulted margin of the complex and the internal structure are revealed in stunning detail on the first vertical derivative and horizontal gradient of the pseudogravity images (Figures 11 and 12), the latter suppressing the anomalies due to dykes and revealing anomalies associated with basement structure. This area is one of poor exposure and low topographic relief and the magnetic data enables the area to be mapped in detail for the first time.

The gradients associated with the Tyrone Igneous Complex form a complex pattern of cross cutting anomalies that represent faulting and shearing of the basic igneous rocks and basic to intermediate volcanic lavas and tuffs.

The margin of the Tyrone Igneous Complex is defined in some places by sinuous curved gradients that represent thrust faulted margins of the magnetic rocks. In other areas the margin is linear in nature where it is bounded by Caledonian trending faults. The southern margin in part appears to be bounded by the Tempo Sixmilecross Fault or a splay of it although the margin here is locally obscured by the non-magnetic Carrickmore granite which itself is probably fault bounded on its northern margin.

The northern margin of the complex is in part bounded by a major fault that has not been mapped. Both of the linear bounding faults have pronounced gravity gradients associated with them and must be related to deep basement faults.

Within the Tyrone Igneous Complex a set of strong linear east northeast lineaments related to faulting and / or shear zones running parallel to the bounding faults. A second set of lineaments has a trend sub parallel to the bounding faults and one of these running through the centre of the Complex is the Beleevnamore Fault that locally disrupts the magnetic anomalies and is marked by a northeast gradient. A third structural magnetic trend is also evident characterised by a series of short arcuate lineaments. It is not clear if these represent an earlier structural fabric.

Both the Tyrone Volcanic Group rocks and those of the Tyrone Plutonic Group are magnetic and also the Corvanaghan Formation of the Central Inlier so these rocks cannot be readily distinguished from each other on magnetic grounds. The northern part of the Tyrone Volcanic Group however has a distinct non magnetic unit so it is not clear exactly where the margin of the Tyrone Igneous Complex occurs.

The northern margin of the magnetic belt is a sharp magnetic contact that lies south of the Omagh Thrust Fault but has a similar arcuate trend to it so it may be a second hitherto unrecognised parallel thrust fault. The magnetic margin lies within the outcrop of the Tyrone Volcanic Group and runs along the southern margin of the Laght Hill Tonalite.

The eastern margin of the complex extends to the east to include the magnetic part of the Tyrone Volcanic Group that is intruded by the granodiorite body at Slieve Gallion. This intrusion must be relatively thin and non magnetic as it does not disrupt the magnetic signature.

4.1.3 Dalradian fold belt

The Dalradian outcrop north of the Omagh Thrust contains an arcuate belt of linear short wavelength positive anomalies associated with rocks of the Southern Highland Group (Figures 11 and 12 domains 3a and 3b). Most of the gradients lie within the outcrop of the Mullaghcam Formation in south County Tyrone where they run parallel to the Omagh Thrust. A second set of arcuate anomalies occur in the Mullaghcam Formation within the Lack Inlier (Figure 8 domain 3c). Both sets of linear features represent magnetic pelitic horizons within the Dalradian sequence of schistose semi-pelite, psammite and pelite and their arcuate form is probably indicative of fold structures. Bedding is not easily recognisable within these rocks so the magnetic anomalies provide important continuous magnetic marker horizons.

One pronounced linear magnetic gradient lies along the contact between the Mullaghcam Formation and the Tyrone Volcanic Group and may be fault related. The main belt of anomalies lie within the Mullaghcam Formation and one strong linear magnetic gradient runs parallel to the outcrop of the Glengawna Formation. Other magnetic linears occur sporadically within the Glenelly Formation. It is possible that the stronger more persistent gradients may be fault related as their trend is parallel to the Omagh Thrust Fault.

Rocks of the Southern Highland Group in south County Tyrone and the Sperrin Mountains on the southern limb of the Sperrin Fold are generally moderately magnetic and gives rise to a broad magnetic high. However the pseudogravity image suggests that some of the high may be attributed to a more extensive high relating to magnetic rocks within the Midland Valley Terrane.

4.1.4 Anomalies over Devonian and Carboniferous rocks

Magnetic anomalies over the Devonian and Carboniferous rocks in County Tyrone and County Fermanagh are broad wavelength anomalies relating to basement rocks.

In broad terms there are two regional magnetic highs (Figure 6 domains 4a and 4b) separated by a pronounced magnetic low 4c. The margin of 4a and 4c is broadly coincident with the Tempo-Sixmilecross Fault confirming the importance of this fault as a major crustal displacement. Magnetic high 4a has an accompanying gravity high (Figure 2) and is probably caused by high susceptibility high density ultrabasic rocks within the concealed Drumore High. Domain 4b may be a continuation of the high susceptibility Ordovician magnetite bearing greywackes found in southwest Scotland. The magnetic low in area 4c is due to low susceptibility Devonian and Carboniferous sedimentary rocks.

4.1.5 Southern Uplands - Down - Longford Terrane

All of the outcrop of Lower Palaeozoic rocks within the Southern Uplands - Down - Longford Terrane is magnetically quiet (Figures 6-8 domain 5). The absence of near surface anomalies suggests the Palaeozoic greywacke and shale sequences are of low susceptibility and of moderate density as they produce intermediate gravity anomalies. Magnetic rocks of the Marchburn

Formation derived from an ophiolitic source within a thrust slice to the south of the Southern Uplands Fault in Scotland do not appear to be present here. There is no obvious response to the numerous Caledonian faults that cross the area although the area SW of Strangford Lough has a graininess in this direction.

There is a broad subtle regional increase in the magnetic anomaly towards the extreme southeast over the Hawick Group greywacke and red shale.

4.1.6 Dyke Swarms

The magnetic anomalies associated with the dyke swarms are the source of the most prominent linear magnetic anomalies that cross Northern Ireland. The full extent of these dykes and the remarkable number of them has only now come to light with the new Tellus airborne data. The dykes are of major importance in unravelling the igneous history of the province and can be used to measure recent displacements along faults. They are also important in determining the regional stress fields at the time of emplacement. General comments are made here regarding their regional setting.

There are three major magnetic dyke swarms that cross Northern Ireland (Figures 6, 8 and 9). The northwest to southeast Donegal-Kingscourt dyke swarm and the prolific NNW-SSE trending dykes that cross counties Antrim and Down are the most obvious ones but a third set of cross cutting WNW-ESE more widely spaced dykes also occur and these appear spatially related to the igneous intrusions in County Armagh and County Down. The Donegal-Kingscourt dykes have a characteristic reversed polarity anomaly and are present across Counties Fermanagh, Tyrone and Armagh. They are concentrated in a broad zone some 50 km wide and are mainly linear in nature. Most dykes are on average 50 - 100 metres wide. There is a notable absence of dykes beyond the large linear magnetic dyke that runs immediately south of and parallel to Lough Erne. This may mark the boundary of a crustal discontinuity. The dyke swarm can be traced on regional images offshore across the Irish Sea and are aligned with a similar trending dyke swarm on Anglesey.

The dykes are displaced by the Tempo-Sixmilecross Fault where there is evidence of post dyke intrusion sinistral displacement. The larger west-northwest trending dykes have a sinistral displacement in the order of 2.5 km. The main northwest trending dykes are displaced in a similar direction by between 1.3 to 1.7 km in the same direction. Some dykes are terminated at the fault or there may be some vertical component to the displacement as well. The dykes therefore suggest that major movement along the Tempo Sixmilecross Fault has taken place on at least two occasions. The sharp topographic expression of the Tempo Sixmilecross Fault and its marked termination of resistive units on the EM data (see section 4.2) suggests the fault has been active in recent times.

Other major faults may have influenced the dyke emplacement as many dyke anomalies appear to be terminated at the Clouger Valley Fault and also many are terminated at the Omagh Thrust or displaced to a deeper level by this fault. Similarly north of the Lack Inlier several dykes are terminated or displaced to a deeper level along a lineament presumably a fault that has no surface expression.

The Antrim County Down dyke swarm consists of hundreds of dykes ranging in thickness from between 1.5 and 5 m wide to more substantial linear dykes a few tens of metres in width. The majority of the dykes are positively magnetised and occur within a broad zone 18 to 20km wide (Figures 6-10 domain 6). This area is shown as a broad positive magnetic ridge in the pseudogravity image and may relate to an igneous basalt magma chamber at depth where the source of much of the basalt dyke material originated. The dykes show an alternating pattern of positive and negative anomalies and there is some symmetry to the pattern. The main positive anomaly seen on regional magnetic data clearly extends into the basalt where it can be traced with certainty as far as the Sixmilewater Fault. Beyond this fault the anomaly becomes lost within similar tending anomalies beneath the Antrim lavas (see section 4.1.1). Many dykes are sinuous in nature but do not appear to cross one another and reflect a complex stress pattern that occurred at the time of emplacement. Sinuous dykes may represent the roots of a line of ancient fissure eruptions.

4.1.7 Igneous intrusions.

The margins of the major intrusive centres of the Caledonian Newry Igneous Complex and the Palaeogene Mourne Mountains, Slieve Gullion and Carlingford complexes are identified by the magnetic survey and the extent of intrusions that have no magnetic expression by the gravity data.

A very pronounced circular magnetic anomaly (Figure 14 domain 7a) is associated with the Palaeogene Slieve Gullion Igneous Complex that is intruded into the late Palaeozoic southwest-trending granodiorite pluton of the Newry Igneous Complex. The magnetic data defines the outer margin of the Newry Igneous Complex as a circular feature that follows the mapped outcrop of the intrusion but probably extends at shallow depth a few kilometres beyond. The exact margin of the intrusion is hard to define because of its multiple nature but the first vertical derivative magnetic pattern (Figure 16) is consistent as far as the outer porphyritic felsite ring and is probably related to the Slieve Gullion Igneous Complex . The internal structure of the latter is revealed in great detail by the pseudogravity horizontal gradient image (Figure 15) which suppresses the effect of the dykes and shows a series of circular gradients associated with several ring dykes. The linear eastern margin of the Newry Igneous Complex granodiorite intrusion is terminated by the Newry Fault. The Camlough Fault displaces both intrusions internally. Radiating away from both intrusions on the northwest margin are a series of dykes depicted by the first. vertical derivative field. On the pseudogravity image the Slieve Gullion Igneous Complex intrusion is by far the most dominant magnetic anomaly.

A large gravity high (Figure 2) is coincident with the Slieve Gullion Igneous Complex indicating a very deep-seated magnetic dense predominantly basic intrusion that extends at depth beneath Carlingford Loch and is thought to be joined at depth with the Carlingford Complex as a gravity cupola.

The central and eastern granodiorite bodies of the Newry Igneous complex give rise to circular magnetic anomalies around the margins of the intrusions (domains 7b and 7c). These are assumed to be caused by granodiorite bodies. The anomaly over the central pluton is broadly coincident with the mapped outcrop of the intrusion but the western margin is influenced by the magnetic anomaly of the adjacent western Newry and Slieve Gullion plutons. The ring structure over the northeast pluton lies within the mapped outcrop and indicates a separate or zoned intrusion. A gravity low occurs over the northeast pluton and the horizontal gravity gradient also suggests that it is a separate intrusion. The ultramafic – intermediate complex further to the northeast has a circular magnetic anomaly pattern with no accompanying gravity low.

The Mourne Mountains intrusion (domain 7d) also exhibits a magnetic high with some dyke like structures associated with its eastern margin The intrusion is less well defined from the magnetic data but it appears to have a Caledonide trend although it is Palaeogene in age. The magnetic anomaly has two distinct magnetic highs that seem to confirm the intrusion has an eastern and western centre. High susceptibility mafic rocks are thought to produce the anomalies.

4.1.8 Other magnetic anomalies

A broad wavelength magnetic anomaly to the southwest of Loch Erne (Figure 6 domain 8) is coincident with a gravity low (Figure 2) and probably represents high susceptibility early Palaeozoic volcanogenic basement rocks beneath a thick lower density Carboniferous sedimentary sequence.

In domain 9 the magnetic low and gravity low reflects a sequence of low susceptibility, low density quartz rich Moine Supergroup rocks within the Loch Derg Inlier.

4.1.9 Terrane boundaries.

Terrane boundaries in Scotland are fairly well defined. The southern margin of the Midland Valley Terrane is defined by a regional magnetic and gravity gradient along the Southern Uplands Fault. Similarly the Highland Boundary Fault terminates the surface outcrop of the Midland Valley Terrane on its northern margin and is defined by a strong gravity gradient, but here the magnetic data suggests the Midland Valley Terrane may extend at depth beneath part of the Dalradian Southern Uplands Group. Magnetic anomalies associated with the Midland Valley itself are for the most part positive. Both major faults cannot be traced with certainty offshore as the gravity and magnetic anomalies are obscured by the Permo Triassic Basins of the Irish Sea. The character of the faults certainly changes as they continue into Northern Ireland.

It is thought that the continuation of the Highland Boundary Fault in Northern Ireland is marked by the Fair Head – Clew Bay Line. Carruthers et al (1997) placed the location of the Fair Head – Clew Bay Line along the line of the Belhavel – Castle Archdale Fault and the Tow Valley Fault both of which have strong gravity and magnetic gradients. The gravity and magnetic linkage between these faults is however far from clear and does not have a pronounced gravity and magnetic expression expected of a major crustal terrane boundary. Likewise the location of the Southern Uplands Fault is based on a regional horizontal magnetic gradient that is for the most part obscured by the Antrim lavas but there is very little gravity expression to accompany it.

The high resolution Tellus aeromagnetic data have successfully resolved short wavelength anomalies associated with near surface geological structures but the data is less appropriate for detecting very long wavelength features associated with crustal boundaries. Upward continuation of the data has not been successful in totally removing the anomalies due to lavas and dykes which obscure the more regional structures because of their very strong magnetisation.

The pseudogravity field however has had some success in removing the short wavelength component of the magnetic field. The Midland Valley Terrane is very tentatively defined as a broad positive magnetic high bounded to the northwest by the Tow Valley Fault and to the southeast along the margin of the low magnetic anomaly where magnetic basement is absent (shown as a dashed line in Figure 10).

4.2 ELECTROMAGNETIC DATA.

The electromagnetic data provide valuable information on the near surface geology. The rocks that make up Northern Ireland show a considerable variation in their electrical properties and where contrasts between geological formations are sufficiently large their geological distribution can be mapped.

The apparent resistivity map (Figure 18) shows the general distribution of the major rock units and linear margins of these blocks show where they are fault bounded. Where the rocks are overlain by a significant cover of conductive drift deposits the response from the bedrock units is suppressed. Where rocks are exposed the penetration of the EM signal is greater.

Over large parts of County Antrim for example domains 1a and 1b, resistivity values are lower than 100 ohm-m. The lavas are characteristically low in value presumably due to surface weathering but are also overlain by conductive drift and thick peat deposits. The lower and upper basalts cannot be readily distinguished from the data.

The Dalradian rocks in the northeast part (domain 2) are however generally highly resistive and form a distinct resistivity high area punctuated in places by isolated conductive exposures of Antrim lavas.

Domains 3a and 3b show low resistivity values less than 100 ohm-m associated with the Lough Neagh Group and Triassic sediments.

Domains 4a and 4b also comprise predominantly intermediate to low resistivity rocks but there are some excellent resistivity contrasts the boundaries of which can be readily mapped from the electromagnetic data notably the resistive contrast between very conductive Carboniferous shales and sandstones of the Meenymore, Bellavally, BenBulban Formations and highly resistive limestones of the Darty Limestone Formation and Knockmore Limestone Member.

Other low to intermediate resistivity rocks occur in two areas (domains 5a and 5b) and are prominent where they are in contact with highly resistive rocks. The former is over the Tournasian Owenkillew Sandstone Group which is clearly fault bounded along its southern margin, and the latter occurs over Carboniferous sandstones where they are surrounded by highly resistive limestones. In domains 5c and 5d moderate resistivity values occur over Fintona Devonian sandstone siltsones, mudstones and conglomerates which clearly define the location of the Fintona Block.

In domains 6a and 6b Carboniferous rocks are predominantly highly resistive, notably conglomerates and sandstones north of the Tempo-Sixmilecross Fault, and the resistivity map clearly shows that these rocks are fault bounded. To the southeast of the Tempo-Sixmilecross Fault highly resistive Carboniferous limestones are clearly visible faulted against more conductive Clogher Valley Formation shales.

On a regional scale high resistivity values occur over most of the older Dalradian rocks in domains 7a, b, c, and d. Quarzites and limestones are very resistive but pelitic rocks are less so. Notable exceptions are linear conductors clearly shown on the conductivity images within the Dalradian rocks south of the Sperrin Mountains. Here both the margins of the Lack Inlier and the outcrop of the Mullaghan Formation are bounded by thin markedly pronounced EM conductors. These appear to be related to major faulting in the case of the Lack Inlier and south of the Sperrin Mountains where they are associated with the Omagh Thrust Fault. The conductor along the northern margin is probably also fault related although the conductor in places lies at the top of the Glengawna formation and may be due to a conductive unit within this formation. Other major faults that give rise to high conductivity anomalies are the Tempo–Sixmilecross Fault and the Clogher Valley Fault that both have a topographic expression.

The outcrop of the Tyrone Igneous complex and the Central Inlier (domain 8) are both defined by highly resistive rocks. There does not appear to be a significant resistivity contrast between them. The granite at Slieve Gallion (domain 9) is also resistive.

Rocks of the Southern Uplands-Down-Longford Terrane are generally moderately to highly resistive but sufficient resistivity contrasts occur within them to show the overall structural tend as that of a northeast trending Caledonian fabric. Many lower resistivity trends are associated with faults that are probably thrust slices separating black shales. Within the terrane there are some prominent northeast trending conductors notably in County Down which transect the Caledonide trend but there is no obvious source for these.

The area occupied by the Slieve Gullion and Newry Igneous Complexes is highly resistive and this is coincident with the magnetic high associated with these intrusions. The high is displaced by the Newry Fault.

4.3 RADIOMETRIC DATA

Radiometric Ternary and Total Count maps covering all of Northern Ireland are included in this report for comparison with the magnetic and electromagnetic data. A preliminary interpretation of the regional anomalies is described by Jones (2007), and briefly summarised here.

The broad scale relationships between the radiometric data and regional solid geology are clearly seen on the Ternary and Total Count maps (Figures 19 and 20).

Palaeogene basalts and overlying sediments (mostly the Lough Neagh Group) have relatively low concentrations of K, eU and eTh (shown as dark areas on the Ternary map and pale blue on the Total Count map). Within this generally low radioelement area much higher values occur over parts of the Dalradian and Palaeozoic sequence within the inlier in north-east County Antrim and also over a small area of rhyolites NE of Lough Neagh. The SE and NW fringes around the basaltic outcrop have moderate K, eU and eTh levels corresponding to the Triassic Sherwood Sandstone Group and parts of the overlying Mercia Mudstone Group.

The Lower Palaeozoic rocks in the SE of Northern Ireland within the Southern Uplands Terrane show characteristically high total count values and high values of all three radioelements (light blue, pink and white areas on the Ternary map). The highest concentrations occur over the acid intrusives of the Newry, Mourne Mountains and Slieve Gullion complexes, as well as generally higher levels in the Hawick Group relative to the Gala Group and older Lower Palaeozoic formations.

The Caledonian intrusives in the Midland Valley Terrane are not generally well defined by the radiometric data but the more basic rocks of the Tyrone volcanic province in places show higher radioelement concentrations than the granitic rocks. The Slieve Gallion Granite and parts of the Pomeroy, Carrickmore and Beragh granites and the Laght Hill Tonalite show relatively high values but these are influenced by the superficial cover which has a different composition to the bedrock. There is very little correlation with the magnetic anomalies in this area.

In the western part of Northern Ireland the radiometric data show juxtaposed areas of variably high and low radioelement content. Generally higher K, eU and eTh values are associated with the upper Dalradian psammites and semipelites of the Southern Highland Group and the overlying Tournaisian Barony Glen Formation in County Londonderry and north County Donegal.

The Dalradian formations of the Sperrin Mountains tend to have generally low values of K, eU and eTh but the signatures here are in part masked by the overlying superficial deposits and there has been much ‘smearing’ of anomalies due to glacial action. To the south of the Sperrin Mountains radiometric data pick out sharp boundaries within or between Dalradian and upper Palaeozoic rocks where their margins are fault bounded.

Upper Palaeozoic rocks southwest of Lough Erne and southeast of the Clogher Valley Fault have characteristically intermediate or low radiometric values shown as blue or black colours on the Ternary map.

5 Mineral prospectivity.

A very preliminary evaluation of the data has been made to evaluate the mineral exploration potential of Northern Ireland using the airborne geophysical data. The extensive Tellus regional database of stream sediment and soil geochemistry data collected for Northern Ireland has not been used for this study as the sample results were not available at the time.

A list of known mineral localities provided by staff in the Belfast office was supplied in an excel spreadsheet and additional data supplied later. The data were coded and split into several point data GIS themes for use as overlays in the GIS. This was deemed necessary to avoid overposting of information and allowed the data to be colour coded using various symbols. The following point layers were created.

- Most important economic mineral occurrences and active mines
- Base metal Cu, Pb, Zn and Ba locations
- Precious metal deposits and their indicators Au, Mo, As
- Bulk mineral deposits including Fe Mn Pyrite and Pyrrhotite
- Gemstones including diamonds, beryllium and others
- Industrial minerals
- Laterite deposits

The digitised lineaments from the magnetic and electromagnetic data and the digital gravity, magnetic electromagnetic and radiometric images all in a GIS format plus the geochemical data has laid the foundation for a more systematic prospectivity study to be carried out in the future.

Spatial correlation of mineral localities with magnetic lineaments, regional magnetic anomalies, electromagnetic conductors and regional gravity features has identified the main prospectivity target in Northern Ireland as that within the area that covers the Upper Dalradian rocks of the Sperrins area, the Omagh Thrust Fault and the sheared rocks of the Tyrone Igneous Complex where this area shows the greatest degree of shearing and faulting (Figures 21-23).

Within the Dalradian outcrop south of the Sperrin Mountains localities where gold has been reported align along an outer semi arcuate zone that is tentatively coincident with a linear local magnetic high. On the horizontal gradient pseudogravity map (Figure 22) many localities lie within a belt of pale blue colours. These anomalies lie at the contact between the Dart and Glenelly Formations (Figure 23).

To the south of this line mainly gold but also lead anomalies are located over at least four prominent arcuate magnetic linear highs within the outcrop of the Mullaghcarn Formation. Other sporadic gold occurrences are also coincident with local magnetic gradients adjacent to the Omagh Thrust Fault. Two of the magnetic arcuate belts are separated by the conductivity anomaly that occurs at the top of or locally within the Glengawna Formation. There do not appear to be many gold deposits recorded south of the Omagh Thrust except for one significant occurrence that lies over a small local magnetic lineament.

A belt of copper and lead deposits occur between the Omagh Thrust Fault and the linear magnetic gradient that marks the margin of the magnetic part of the Tyrone Igneous Complex. Two copper occurrences lie on the pronounced linear magnetic gradient over the Omagh Thrust Fault and there is a cluster of copper anomalies over the thrust coincident with a local magnetic high over the northeast margin of the non magnetic part of the Tyrone Igneous Complex.

The rest of the copper and lead and zinc deposits are found in the non magnetic Tyrone Volcanic Group and appear to plot in a line that mirrors the trend of the magnetic gradient along the margin of the Tyrone Igneous Complex. Most localities are along the northwest margin of the Laght Hill tonalite. The copper and lead belt here lies within a broad magnetic low on the reduced to pole map but there is a subtle lineament within this zone where most of the deposits are clustered.

At the margins of the Tyrone Igneous Complex copper anomalies are located over magnetic horizontal gradient maxima which are mainly linear and may be related to faults.

A notable cluster of barium occurrences occurs along the northern margin of the Slieve Gallion intrusion. Other sporadic isolated barium and copper localities appear to be dyke related. The barium and copper localities mentioned above are broadly coincident with NNE trending gravity gradients the significance of this correlation is yet to be determined.

In terms of a prospectivity model for the area there is a strong relationship between recorded mineralisation and geological structure. There is a clear association with magnetic anomalies that depict a series of arcuate structures within which mineralisaton is located in distinct belts. Mineralisation is concentrated in areas of shearing and faulting which increase in the Dalradian towards the Omagh Thrust and the Midland Valley Terrane Tyrone Igneous Complex. Magnetic lineaments and EM conductors suggest a series of deep thrusts and shear zones which have the potential to provide conduits for mineralization. A prospectivity study of this area is highly recommended.

Some gold locations in the Dalradian north of the Sperrin Mountains (Figure 21) appear to align along an ENE trend concordent with the Dalradian strike while others lie on the margins of pseudogravity horizontal gradient highs but the relationship with magnetic anomalies is far from clear.

Elsewhere in Northern Ireland some lignite deposits are located on magnetic gradients at the margins of or within the Antrim lavas. Similarly many laterite and diatomite clusters are found within magnetic anomalies related to basalt lavas.

There are clusters of beryllium iron copper lead and zinc within a pseudogravity horizontal gradient low characteristic of the medium and fine grained granites of the Eastern Mournes Centre.

Clusters of iron and pyrite occur over the ultramafic magnetic part of the Newry Igneous Complex. The Slieve Gullion and most of the Newry Igneous Complex have no recorded minerals.

There are clusters of lead mineralization within the lower Palaeozoic rocks in County Armagh but there is no obvious geophysical anomaly associated with these although they are in close proximity to the magnetic dyke swarm that radiates out from the Slieve Gullion Igneous Complex.

Around Bangor clusters of lead and zinc anomalies are coincident with a gravity high crossed by the Orlock Bridge Fault. Copper lead and zinc anomalies also occur over a wide area of the Hawick Group greywacke and shale but they are not associated with any particular geophysical anomaly.

In terms of mineralisation throughout the province it is recommended that the list of mineral occurrences is updated and further classified. Enough shear zones and new faults have been identified from the geophysics that have the potential to provide paths for mineralised fluids to flow.

6 Conclusions

For the preliminary regional interpretation of the Tellus airborne geophysical data, many high resolution images of the magnetic, electromagnetic and radiometric data were generated and incorporated into a GIS system along with existing regional gravity, digital geological mapping and mineral occurrences data.

The GIS has proven a powerful tool for analysing these data at both regional and local scales for geological mapping purposes, and the Tellus data have provided a wealth of new information about the geology, regional structure and mineral potential of Northern Ireland.

Magnetic anomalies associated with the Antrim basalts dominate the aeromagnetic map and their strong magnetic signature allows the surface extent of the lavas to be mapped accurately in areas of poor exposure. The pseudogravity and pseudogravity horizontal gradient maps have been particularly effective in identifying structures within the basalt outcrop including lineaments associated with faulted block margins some of which are coincident with bounding faults of sedimentary basins.

In the southern part of County Tyrone the margins of the Tyrone Igneous Complex and the internal structure of the complex itself are revealed in stunning detail on the first vertical derivative and pseudo gravity horizontal gradient maps. This area is one of poor exposure and low topographic relief and the magnetic data enables this area to be mapped in detail for the first time. Many new faults are revealed and the sheared nature of the rocks is apparent. Linear bounding faults have strong gravity gradients associated with them and must be related to deep basement faults. Magnetic and non-magnetic suites of rocks within the complex have also been identified.

In northern County Tyrone the magnetic data have revealed a belt of arcuate linear short wavelength positive anomalies within the Southern Highland Group Dalradian outcrop north of the Omagh Thrust, and within the Lack Inlier. Both sets of linear features represent magnetic horizons within the Dalradian sequence and their arcuate form is probably indicative of fold structures. Bedding is not easily recognisable within these rocks so the magnetic anomalies provide important continuous magnetic marker horizons.

The full extent of the dyke swarms that cross Northern Ireland has only now come to light with the new Tellus airborne data. There are three major magnetic dyke swarms, the northwest to southeast Donegal-Kingscourt dyke swarm, the prolific NNW-SSE trending dykes that cross counties Antrim and Down, and a set of cross cutting WNW-ESE more widely spaced dykes that appear spatially related to the igneous intrusions in County Armagh and County Down. Most of the Antrim County Down dyke swarm is concentrated within a broad zone 18 to 20 km wide and exhibits a symmetrical pattern and the more sinuous dykes may mark the line of fissure eruptions.

Igneous dykes can be used to measure recent fault displacements and the magnetic data indicate that major sinistral movement has taken place along the Tempo-Sixmilecross Fault on at least two occasions. The sharp topographic expression of the fault and its marked termination of resistive units on the EM data suggests it may have been active in recent times.

The margins of the major intrusive centres of the Newry Igneous Complex and the Palaeogene Mourne Mountains, Slieve Gullion and Carlingford complexes are identified by the magnetic survey and the extent of intrusions that have no magnetic expression by the gravity data. In particular the Slieve Gullion Igneous Complex whose internal structure is revealed in great detail by the pseudogravity horizontal gradient image and shows a series of circular ring dykes within it.

The high resolution Tellus aeromagnetic survey has successfully resolved short wavelength anomalies associated with near surface geological structures but the data has been less appropriate in detecting very long wavelength features associated with terrane boundaries.

The electromagnetic data provide valuable information on the near surface geology. The rocks that make up Northern Ireland show a considerable variation in their electrical properties and where contrasts between geological formations are sufficiently large their geological distribution can be mapped. For example there is a notable contrast between very conductive Carboniferous shales and sandstones of the Meenymore, Bellavally, BenBulban Formations and highly resistive limestones of the Darty Limestone Formation and Knockmore Limestone Member. Strong linear anomalies occur where these rocks are fault bounded. Likewise the Antrim basalts are characteristically low in resistivity presumably due to surface weathering and the presence of conductive drift and thick peat deposits, whereas Dalradian rocks by contrast are generally highly resistive. Some strong linear conductors have been identified related to faults and shear zones.

The main mineral prospectivity target in Northern Ireland identified from the Tellus geophysical data lies within the area covering the Upper Dalradian rocks of the Sperrins area, the Omagh Thrust Fault and the sheared rocks of the Tyrone Igneous Complex where this area shows the greatest degree of shearing and faulting.

Magnetic anomalies depict a series of arcuate structures within which mineralisation is located in a series of distinct belts. The outer belts contain mainly gold occurrences many of which are located on linear magnetic highs. An inner belt between the Omagh Thrust Fault and the northern margin of the magnetic part of the Tyrone Igneous Complex contains mainly base metal mineralisation. The mineralisation thus appears to be spatially related to shearing and faulting which progressively increases in the Dalradian towards the Omagh Thrust and the Tyrone Igneous Complex.

Magnetic lineaments and EM conductors suggest a series of inferred thrusts and shear zones which have the potential to provide conduits for mineralization. A prospectivity study of this area is highly recommended.

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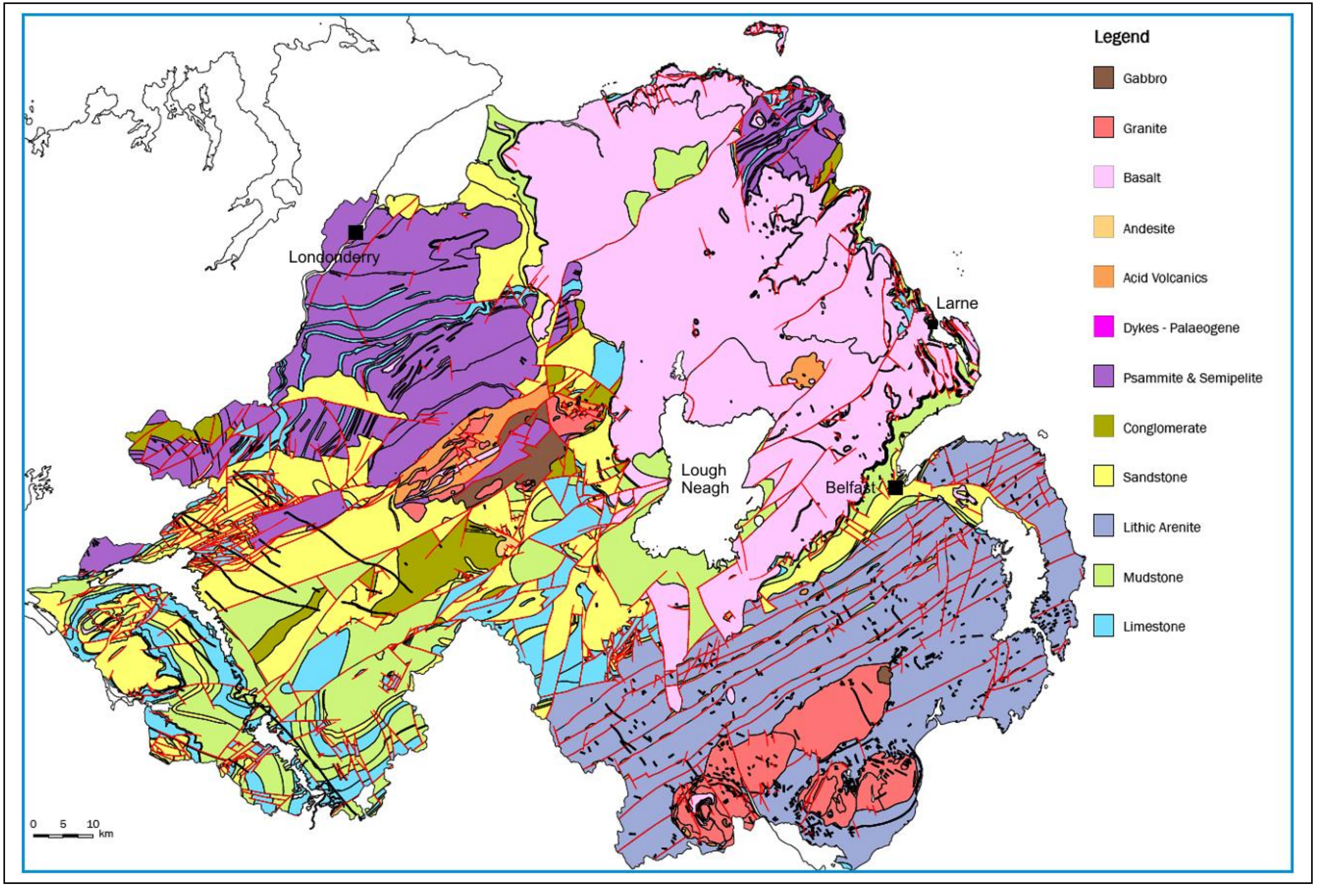

Figure 1 Simplified geological map of Northern Ireland

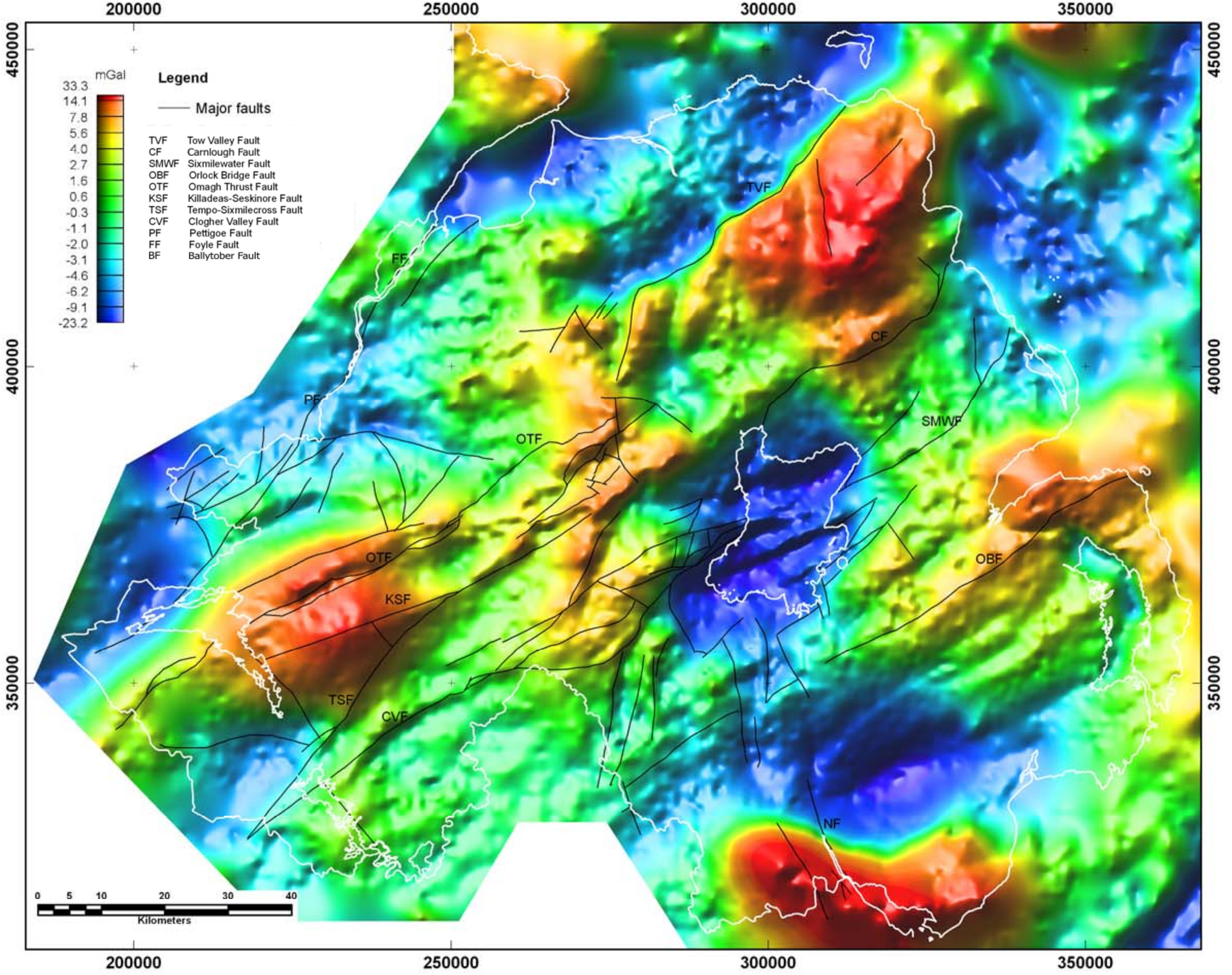

Figure 2 Residual Bouguer gravity anomaly map of Northern Ireland. Colour shaded relief image illuminated from the north.

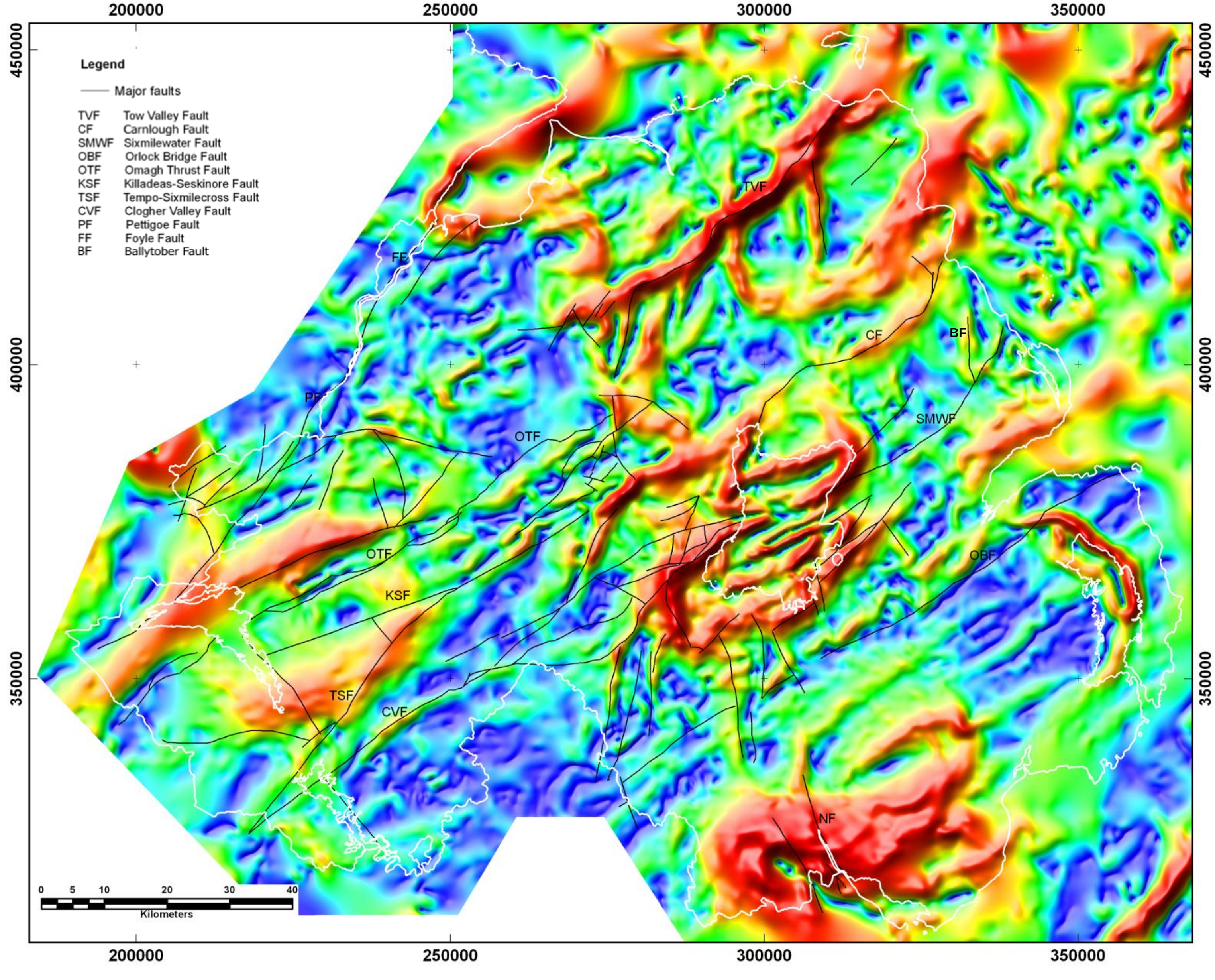

Figure 3 Residual Bouguer gravity anomaly - horizontal gradient map of Northern Ireland. Colour shaded relief image illuminated from the north

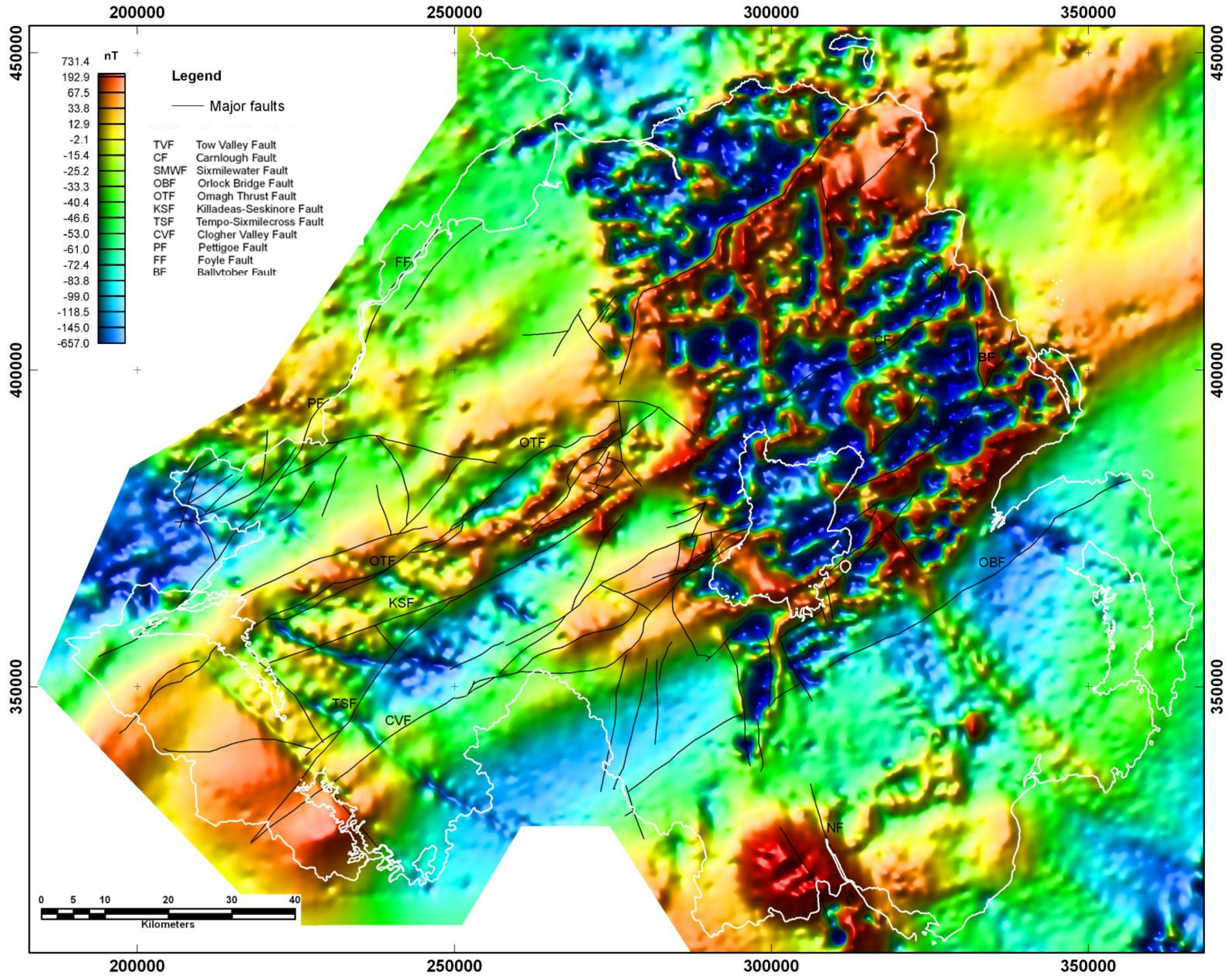

Figure 4 Reduced to pole aeromagnetic anomaly map derived from previous survey data. Colour shaded relief image illuminated from the north.

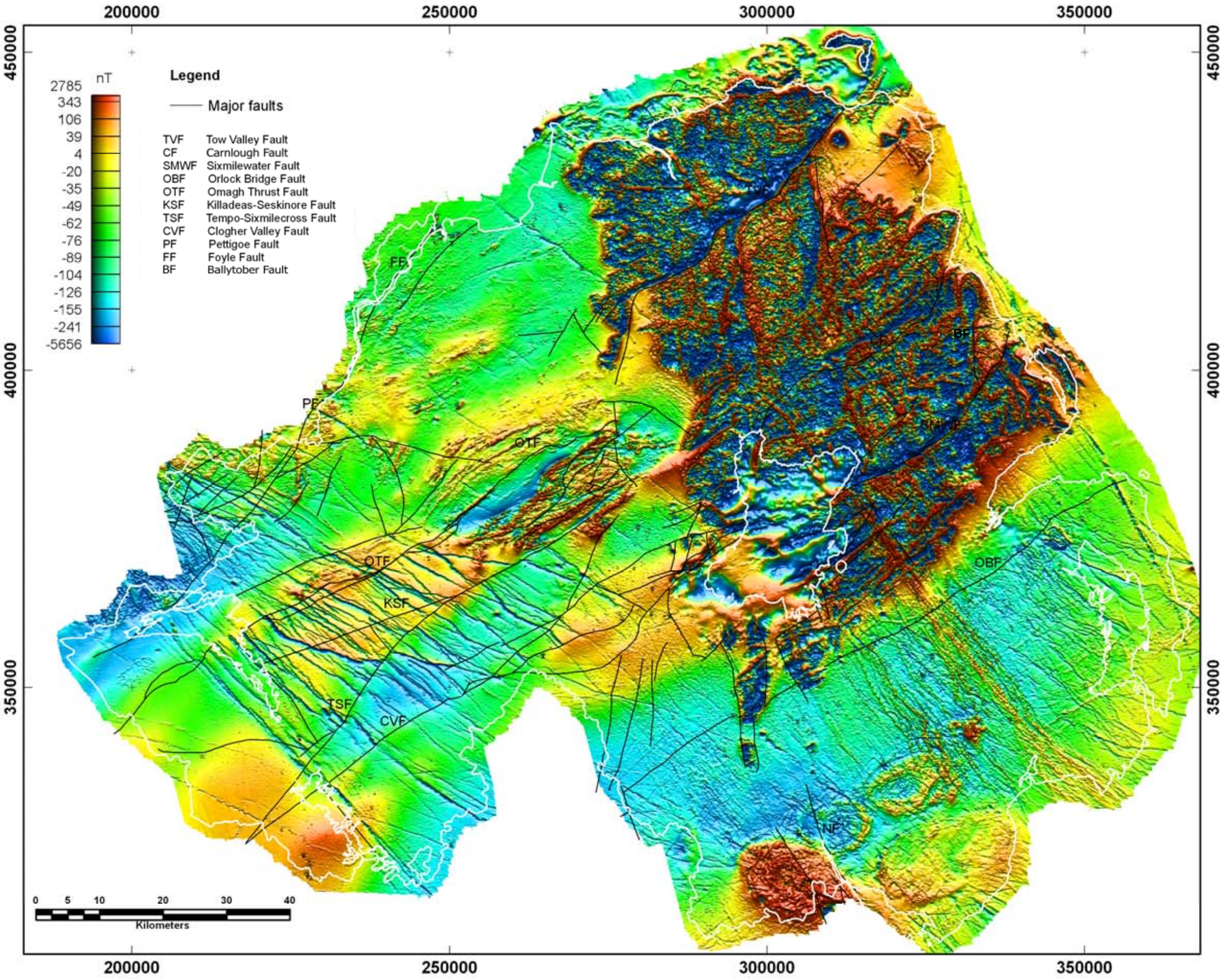

Figure 5 Total Magnetic Intensity anomaly map of Northern Ireland. Colour shaded relief image illuminated from the north.

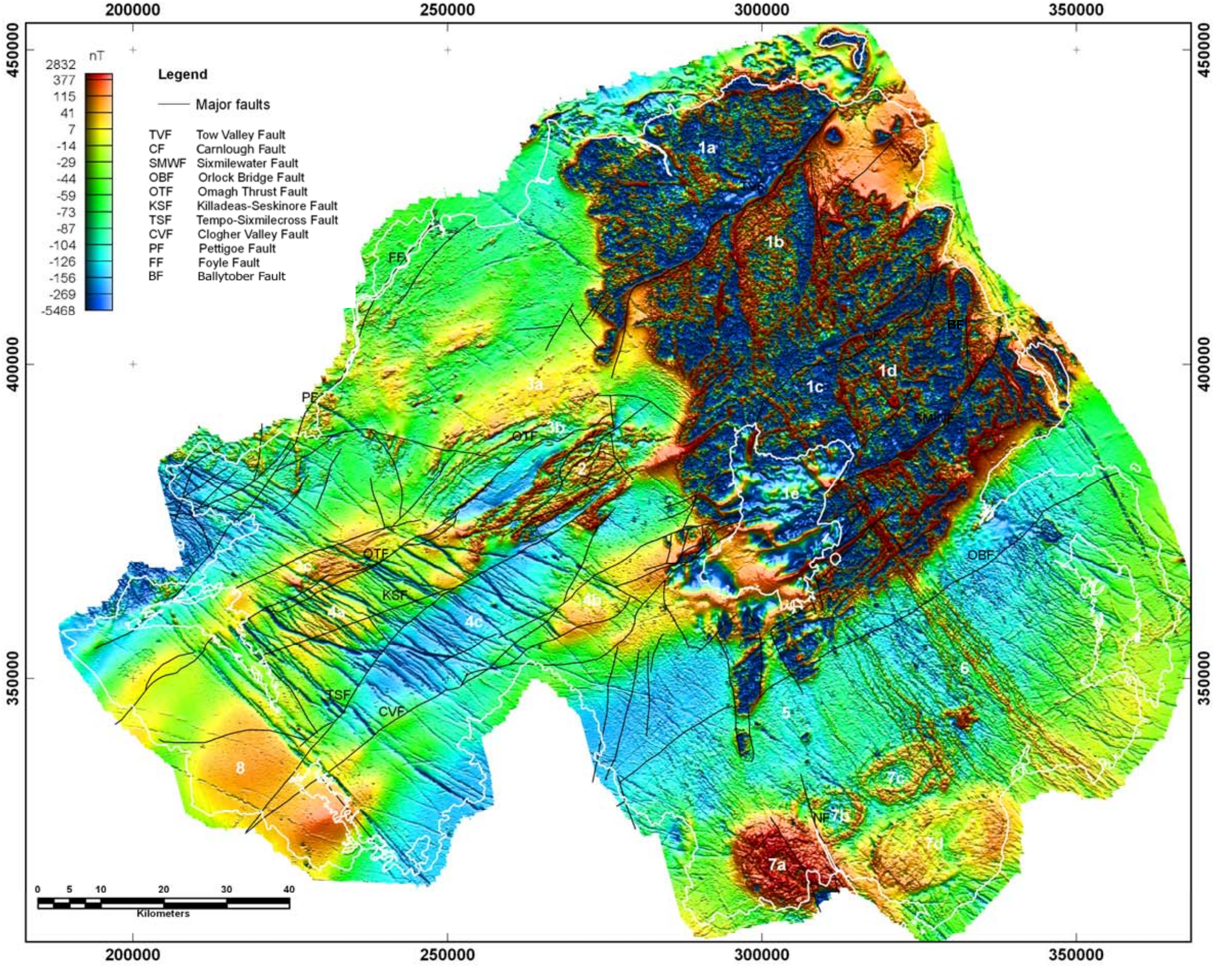

Figure 6 Reduced to pole magnetic anomaly map of Northern Ireland. Numbers are magnetic domains referred to in the report. Colour shaded relief image illuminated from the north.

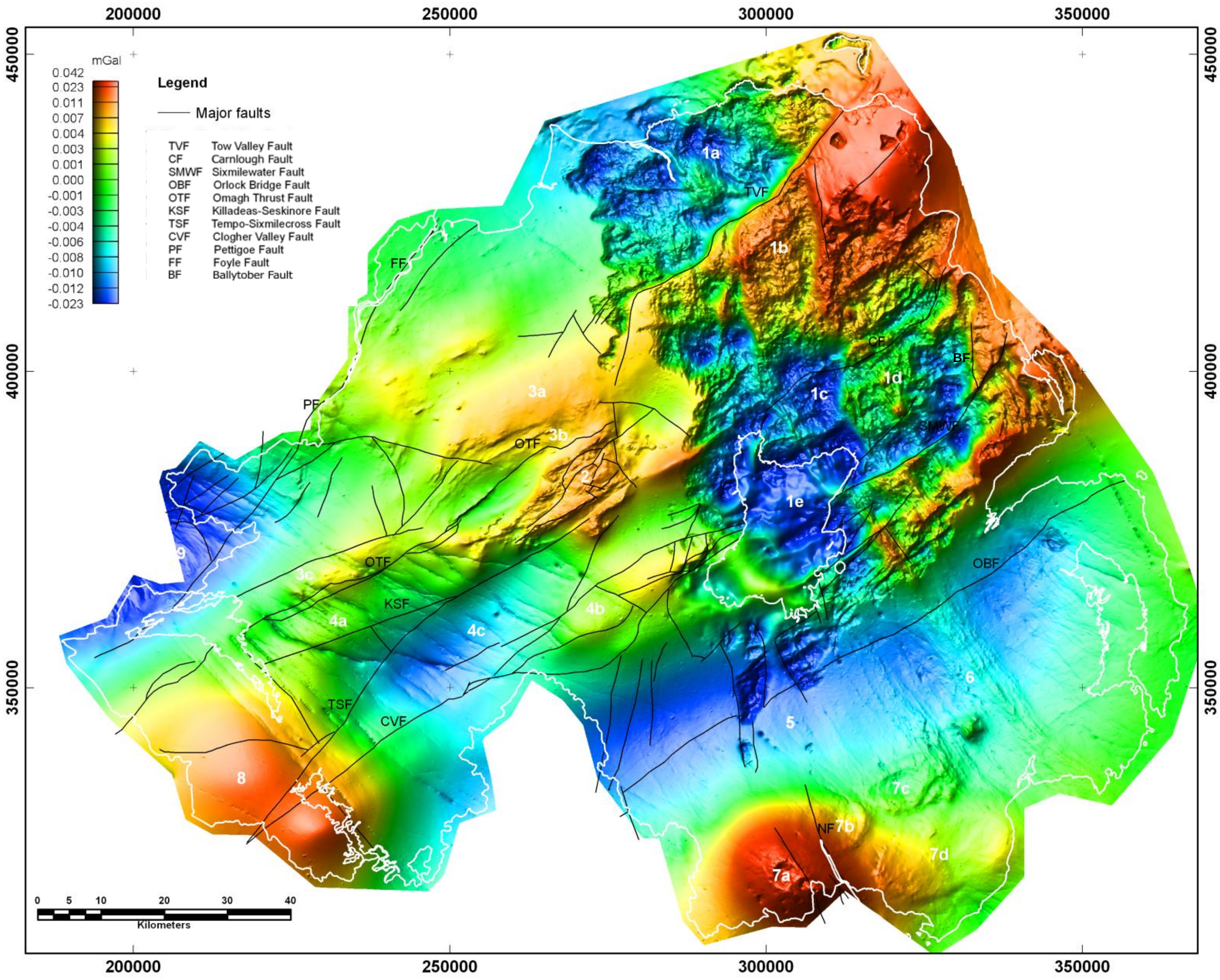

Figure 7 Magnetic pseudogravity anomaly map of Northern Ireland. Numbers are magnetic domains referred to in the report. Colour shaded relief image illuminated from the north west.

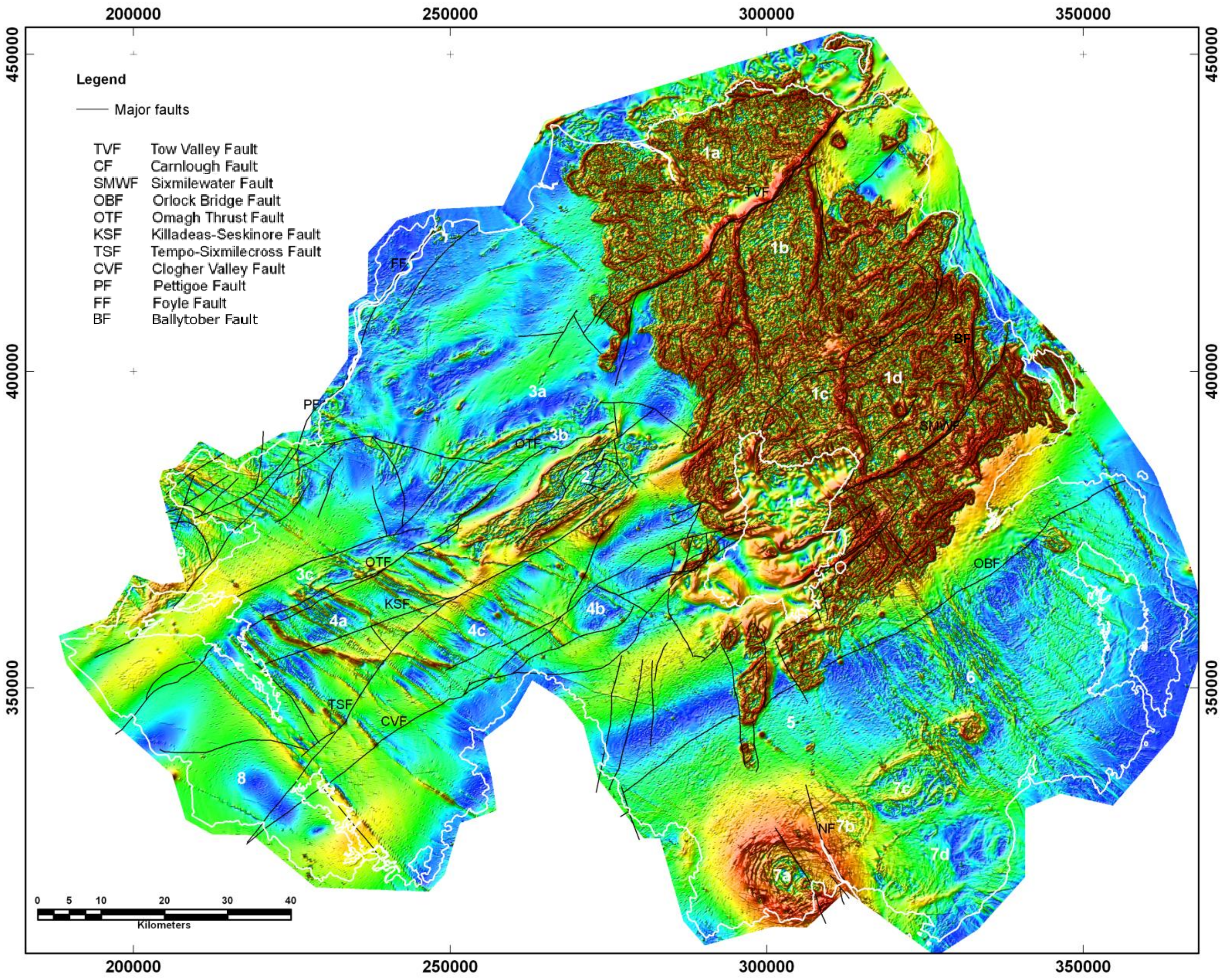

Figure 8 Magnetic pseudogravity horizontal gradient anomaly map of Northern Ireland. Numbers are magnetic domains referred to in the report. Colour shaded relief image illuminated from the north west.

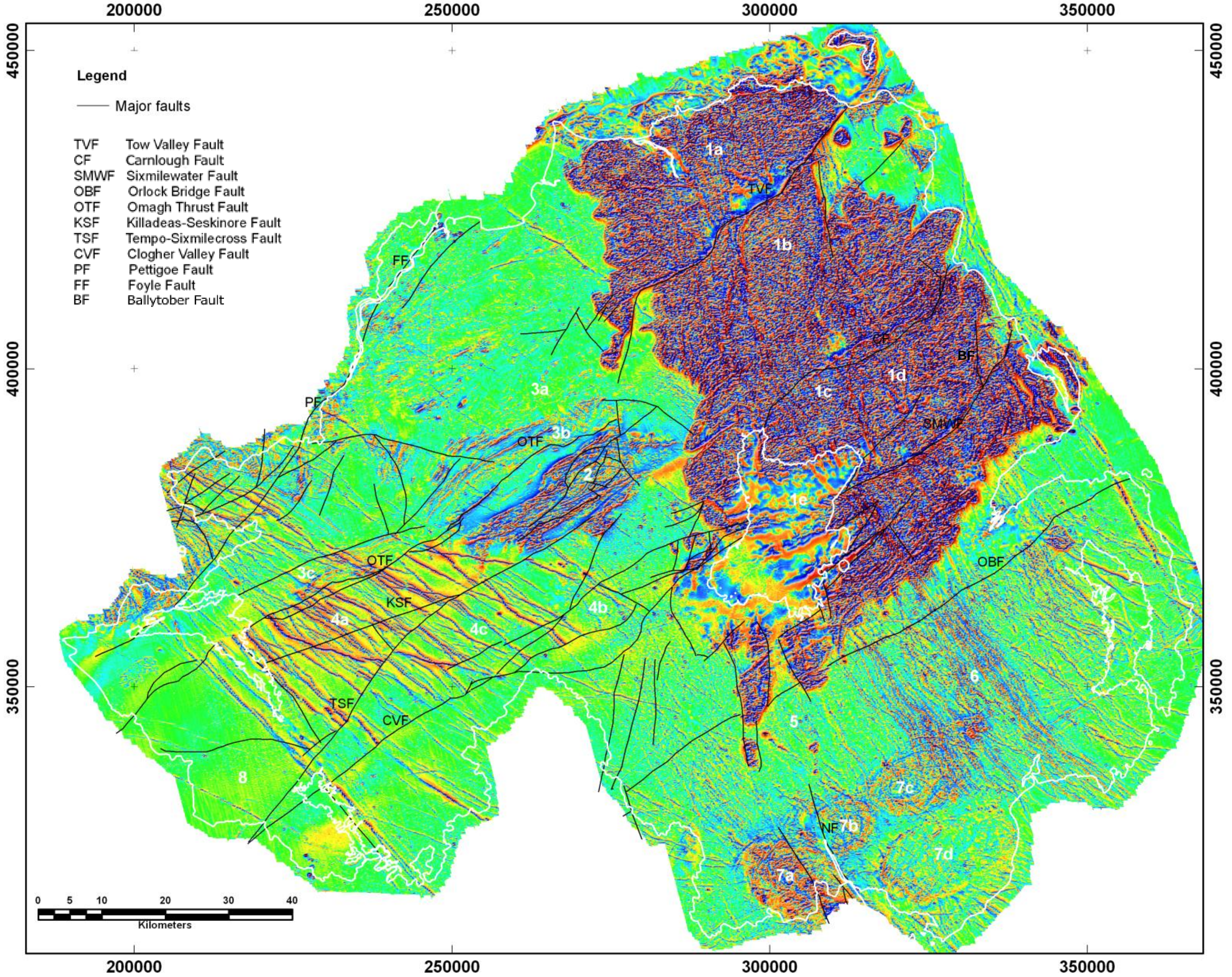

Figure 9 Reduced to pole 1st vertical derivative magnetic anomaly map of Northern Ireland. Numbers are magnetic domains referred to in the report. Colour shaded relief image illuminated from the north.

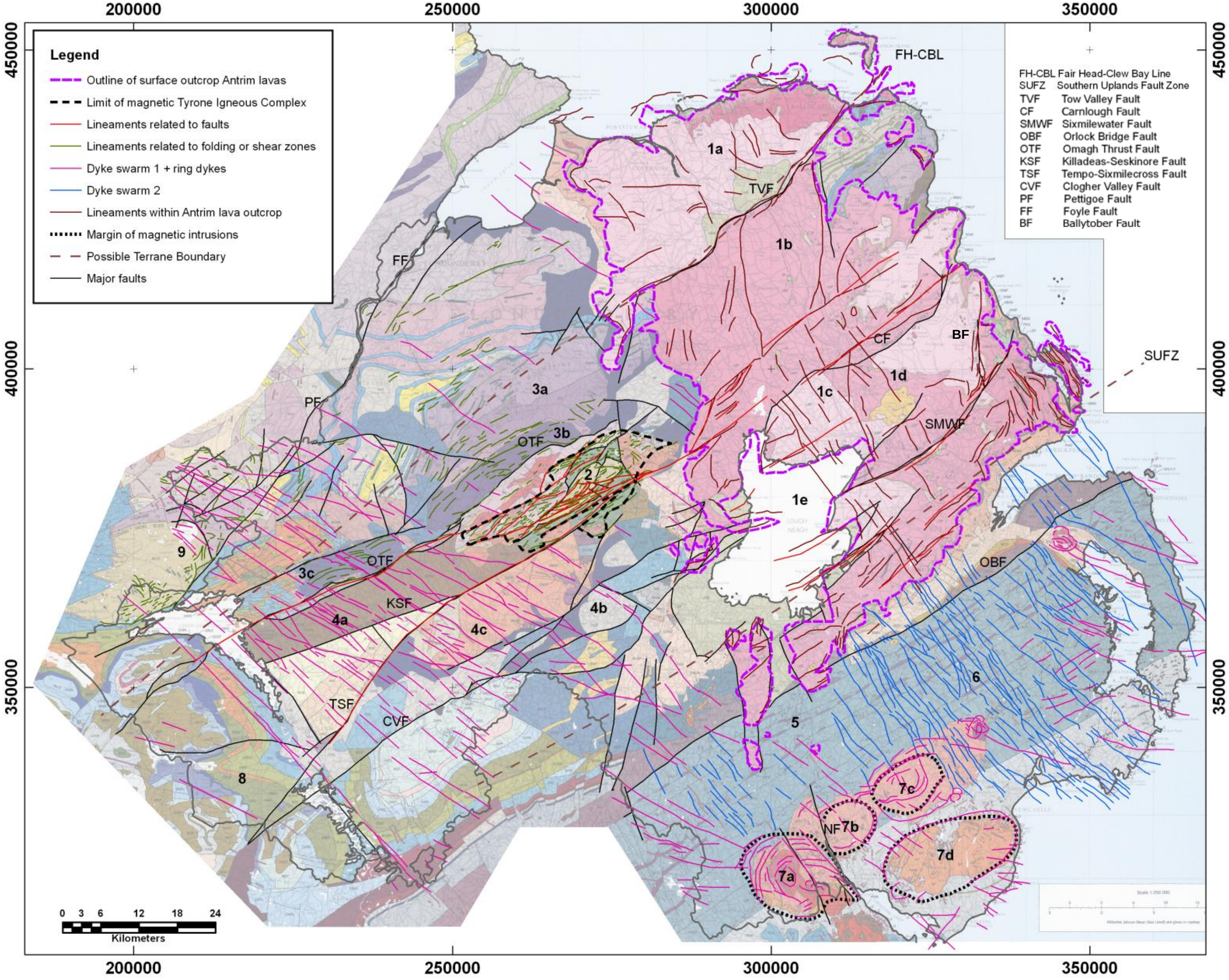

Figure 10 Magnetic structural interpretation map of Northern Ireland. Numbers are magnetic domains referred to in the report. Features are overlain on the GSNI 1:250 000 scale solid geology map.

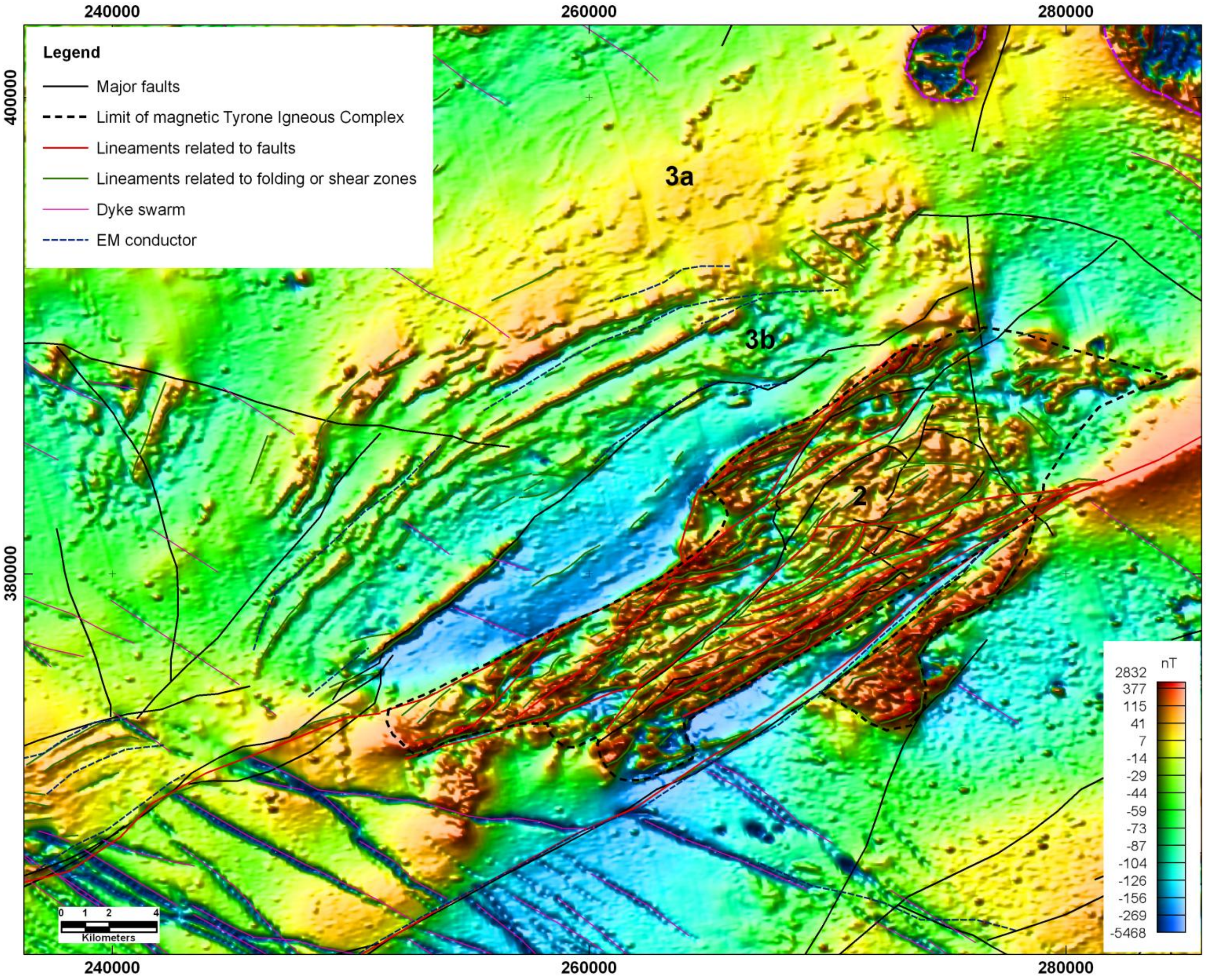

Figure 11 Reduced to pole magnetic anomaly map of the Tyrone Igneous Complex and Dalradian rocks of County Tyrone. Colour shaded relief image illuminated from the north west. Magnetic domains are numbered as referred to in the report. Magnetic features interpreted from various magnetic images are overlain.

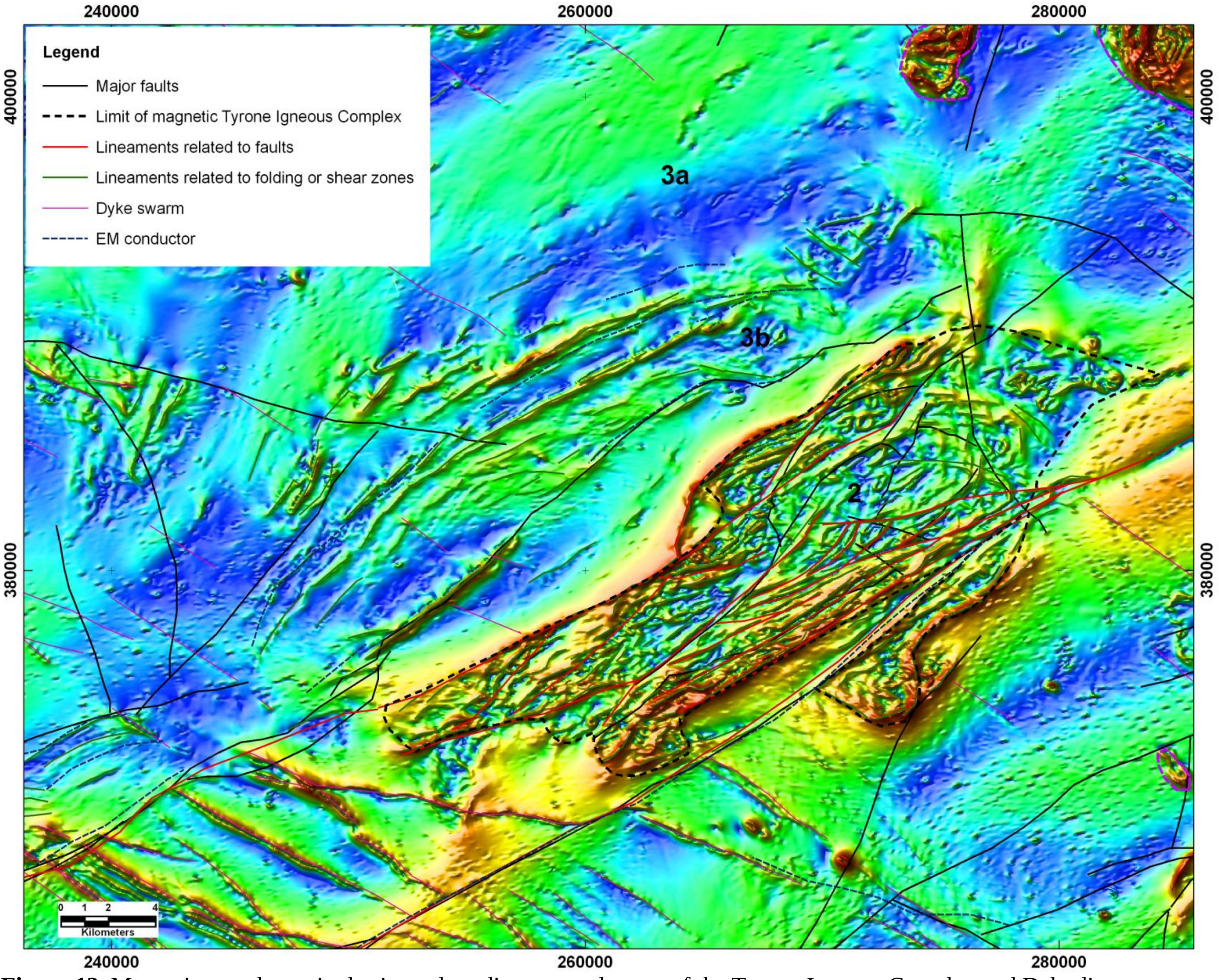

Figure 12 Magnetic pseudogravity horizontal gradient anomaly map of the Tyrone Igneous Complex and Dalradian rocks of County Tyrone. Colour shaded relief image illuminated from the north west. Magnetic domains are numbered as referred to in the report. Magnetic features interpreted from various magnetic images are overlain.

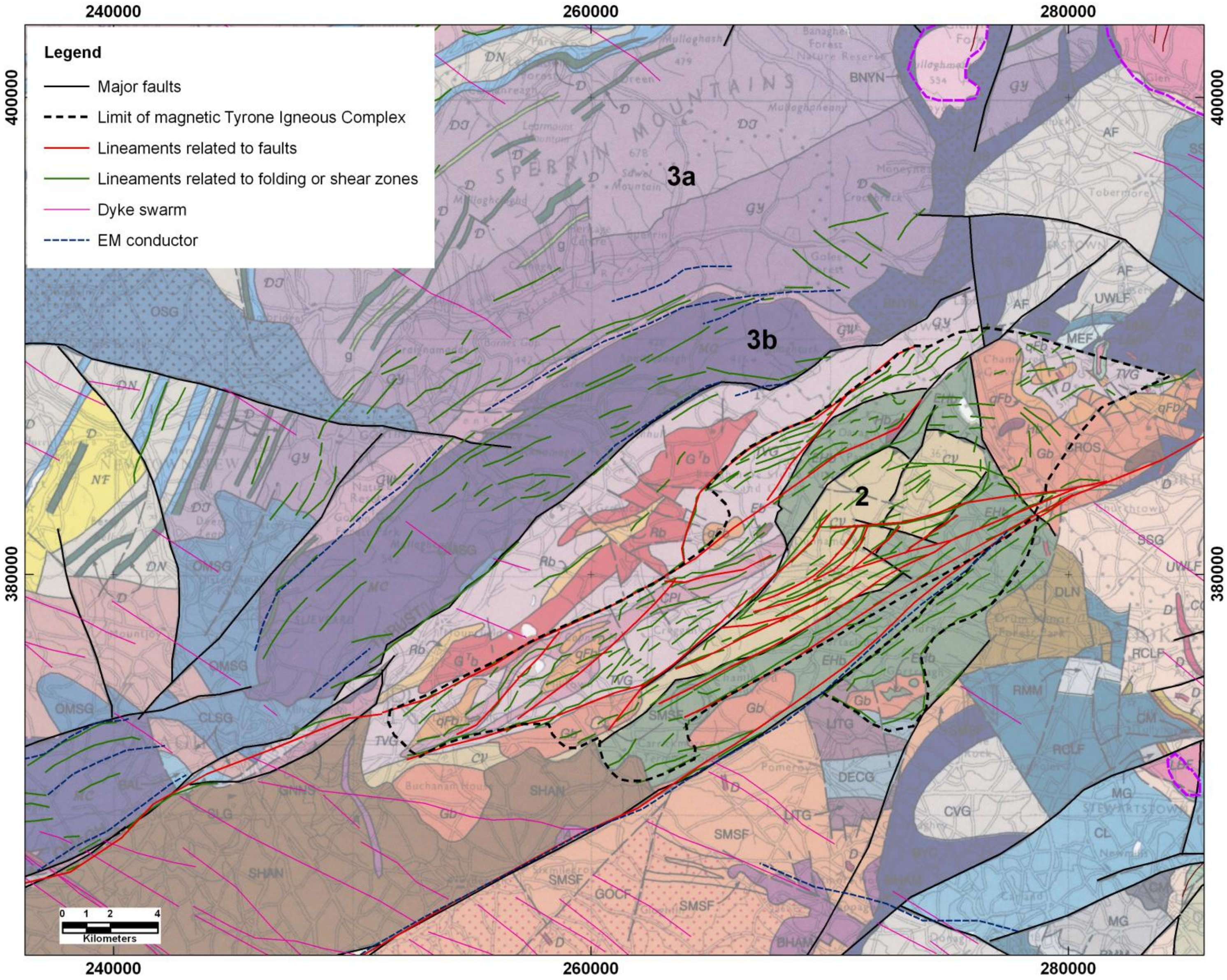

Figure 13 Magnetic structural interpretation map of the Tyrone Igneous Complex and Dalradian rocks of County Tyrone. Magnetic domains are numbered as referred to in the report. Features are overlain on the GSNI 1:250 000 scale solid geology map.

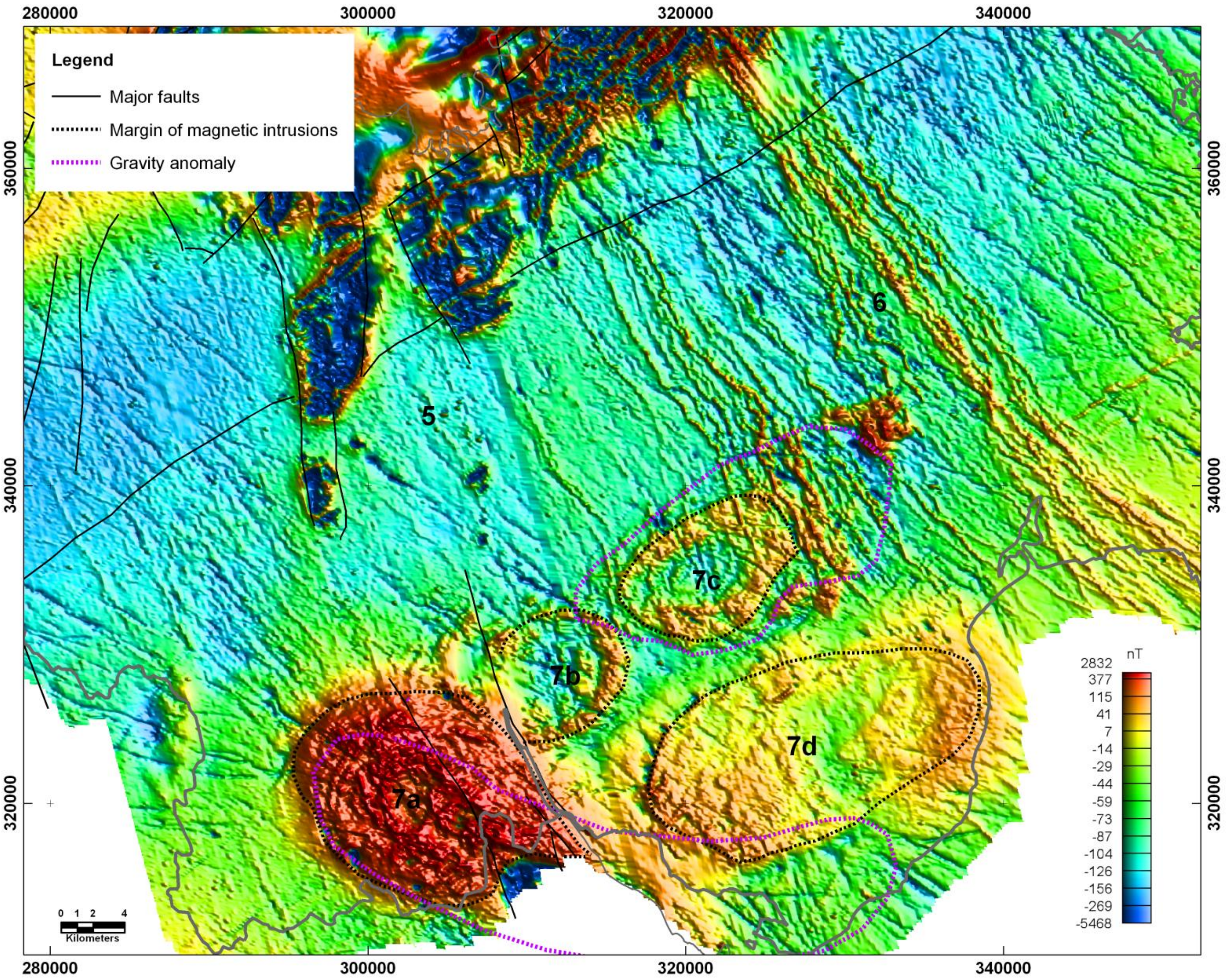

Figure 14 Reduced to pole magnetic anomaly map over of the intrusive igneous rocks of Counties Down and Armagh. Colour shaded relief image illuminated from the north east. Magnetic domains are numbered as referred to in the report.

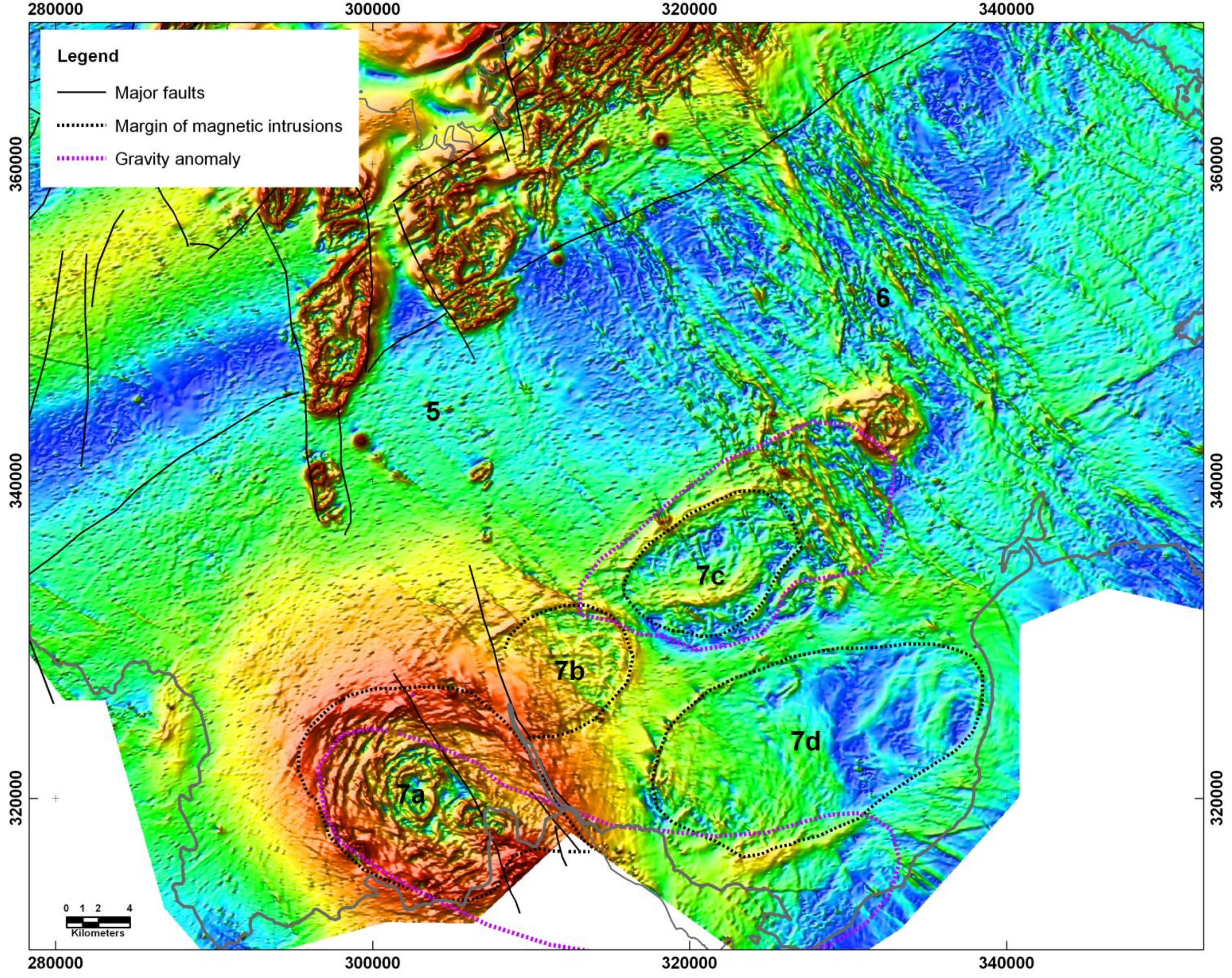

Figure 15 Magnetic pseudogravity horizontal gradient anomaly map over of the intrusive igneous rocks of Counties Down and Armagh. Colour shaded relief image illuminated from the north east. Magnetic domains are numbered as referred to in the report.

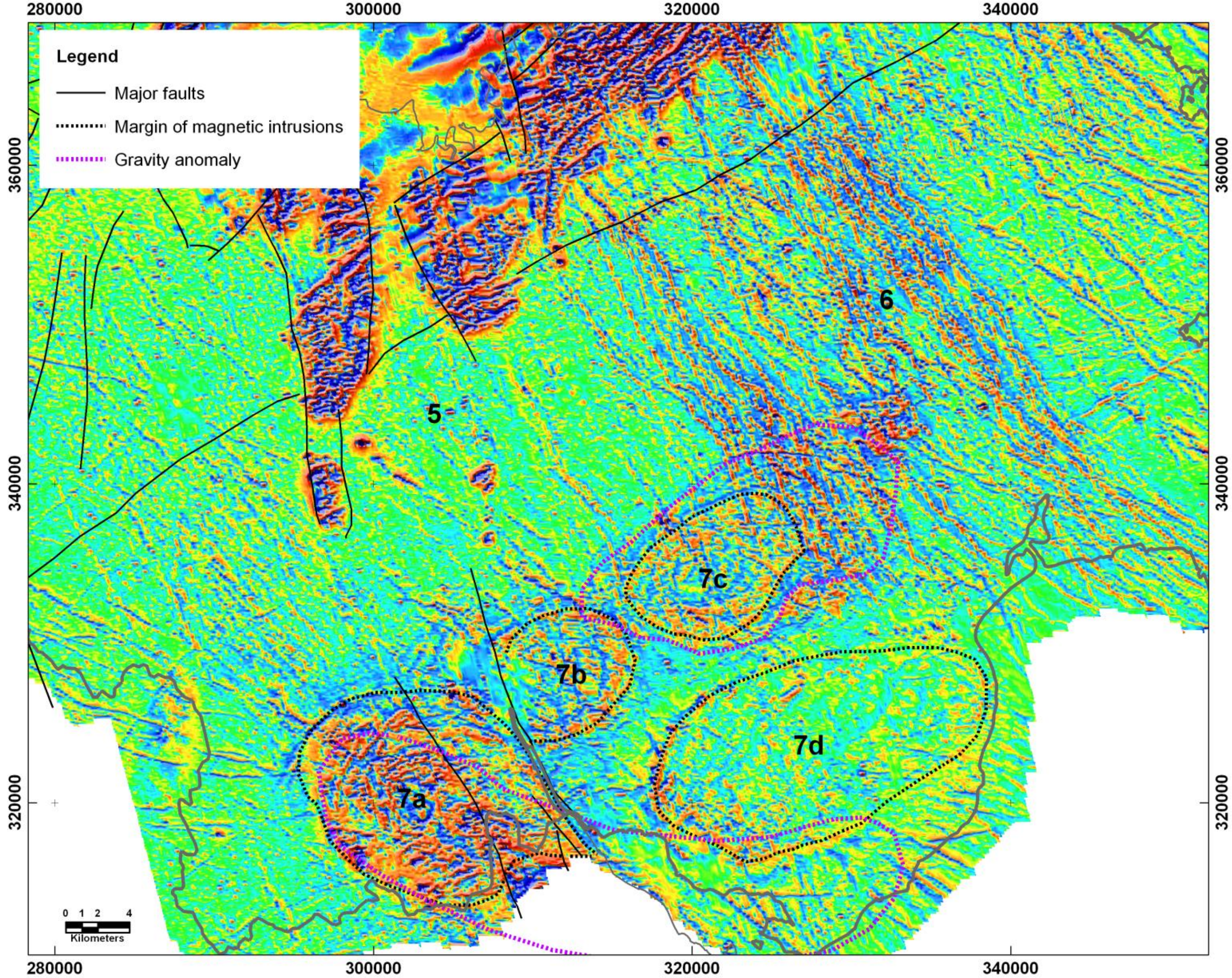

Figure 16 Reduced to pole 1st vertical derivative magnetic anomaly map over of the intrusive igneous rocks of Counties Down and Armagh. Colour shaded relief image illuminated from the north east. Magnetic domains are numbered as referred to in the report.

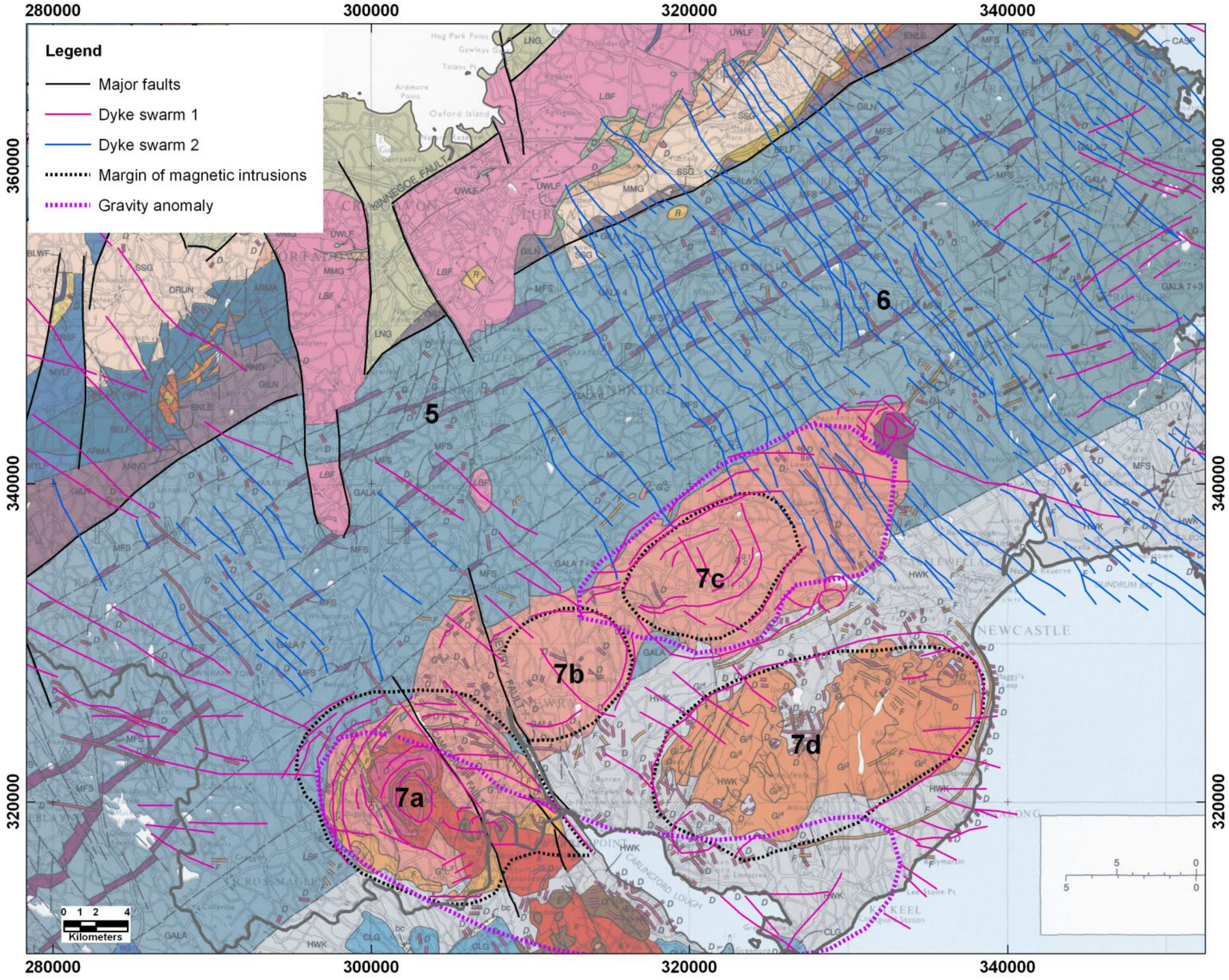

Figure 17 Magnetic structural interpretation map over of the intrusive igneous rocks of Counties Down and Armagh. Colour shaded relief image illuminated from the north east. Magnetic domains are numbered as referred to in the report. Features are overlain on the GSNI 1:250 000 scale solid geology map.

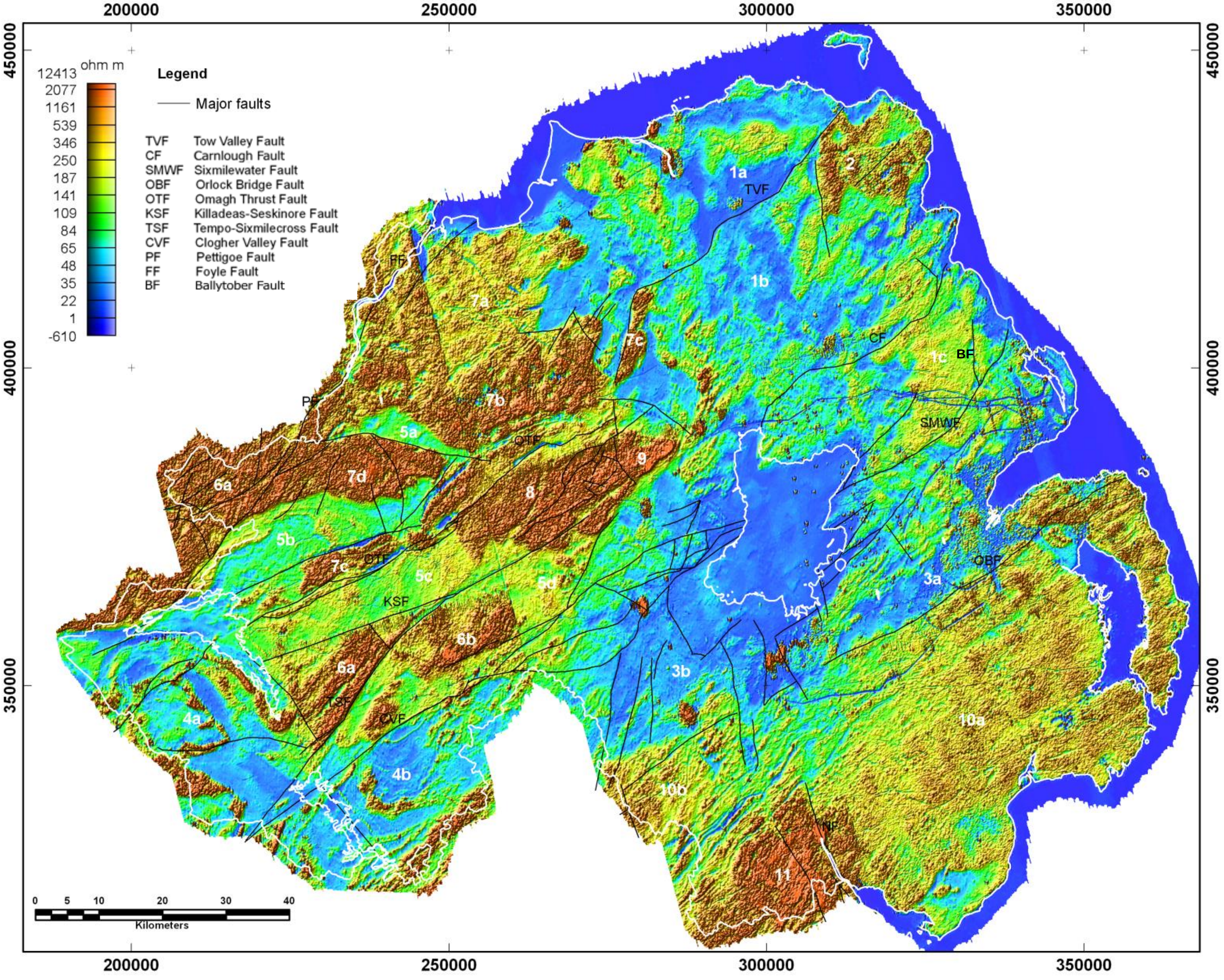

Figure 18 Electromagnetic apparent resistivity anomaly map of Northern Ireland. EM domains are numbered as referred to in the report. Colour shaded relief image illuminated from the north.

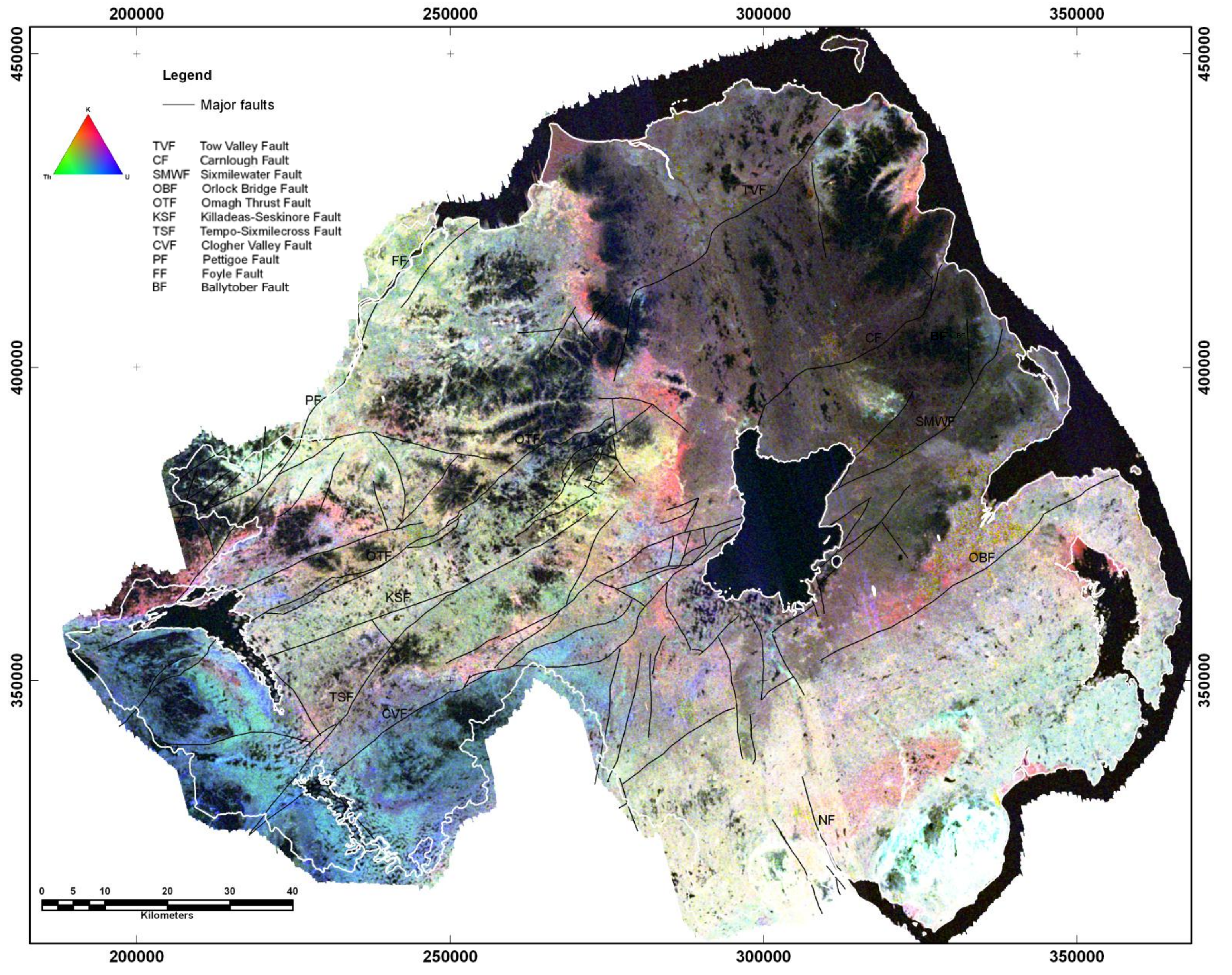

Figure 19 Ternary radiometric anomaly map of Northern Ireland.

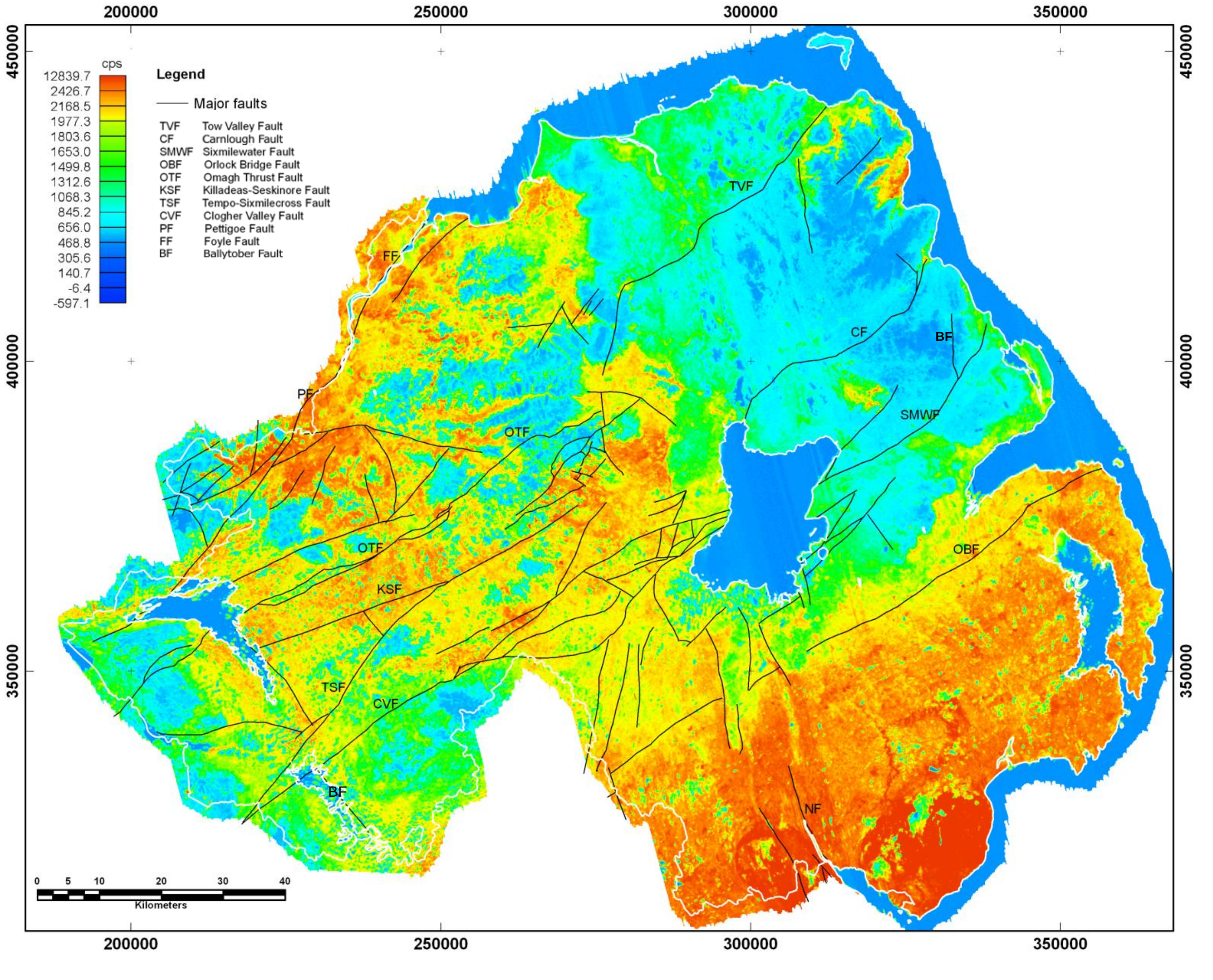

Figure 20 Total Count radiometric anomaly map of Northern Ireland.

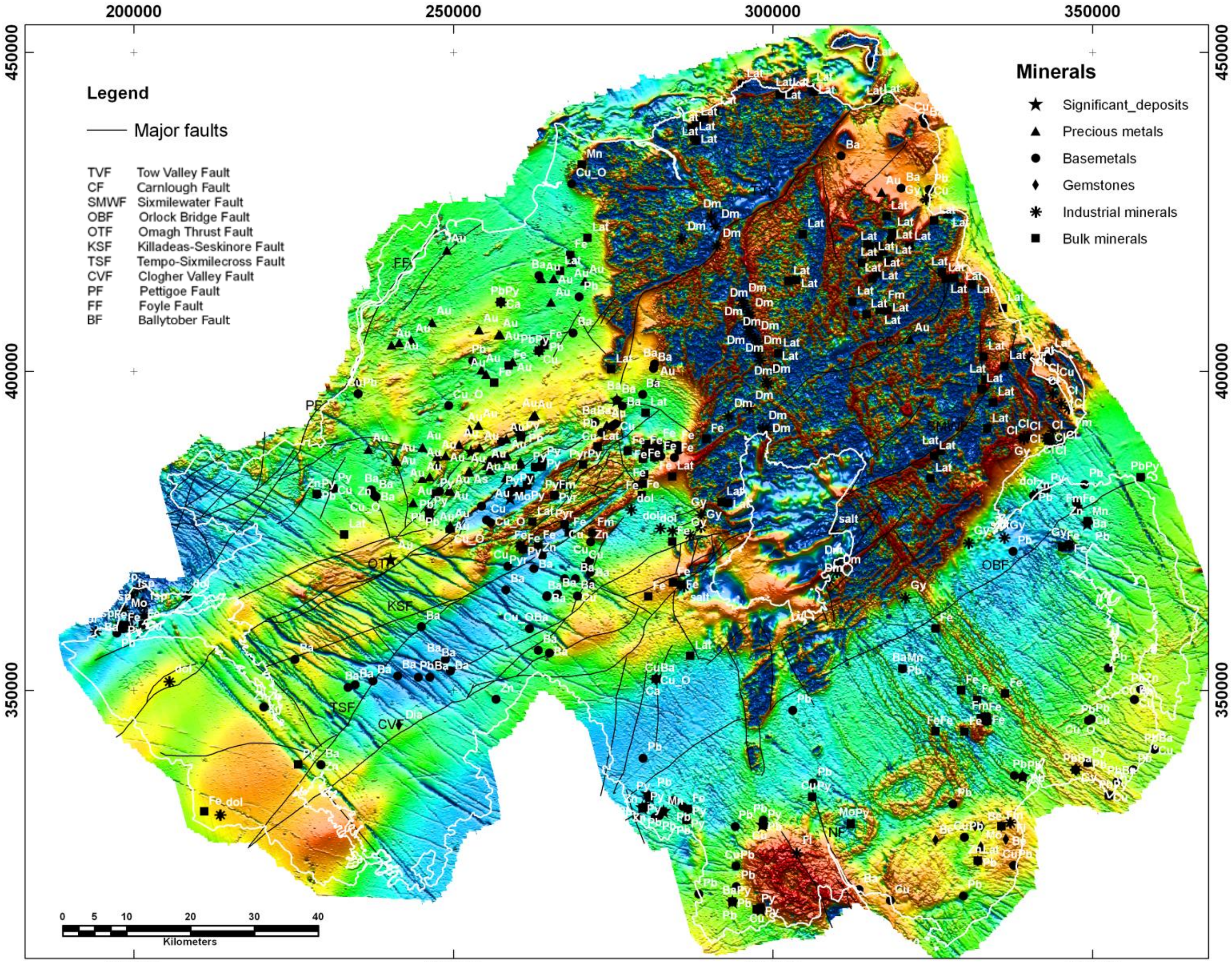

Figure 21 Reduced to pole magnetic anomaly map of Northern Ireland with reported mineral localities. Colour shaded relief image illuminated from the north. Minerals are labelled as elements except for Pyrite (Py), Pyrrhotite (Pyr), Laterite (Lat), Dolomite (dol), Diatomite (Dm), Gypsum (Gy), Diamonds (Dia).

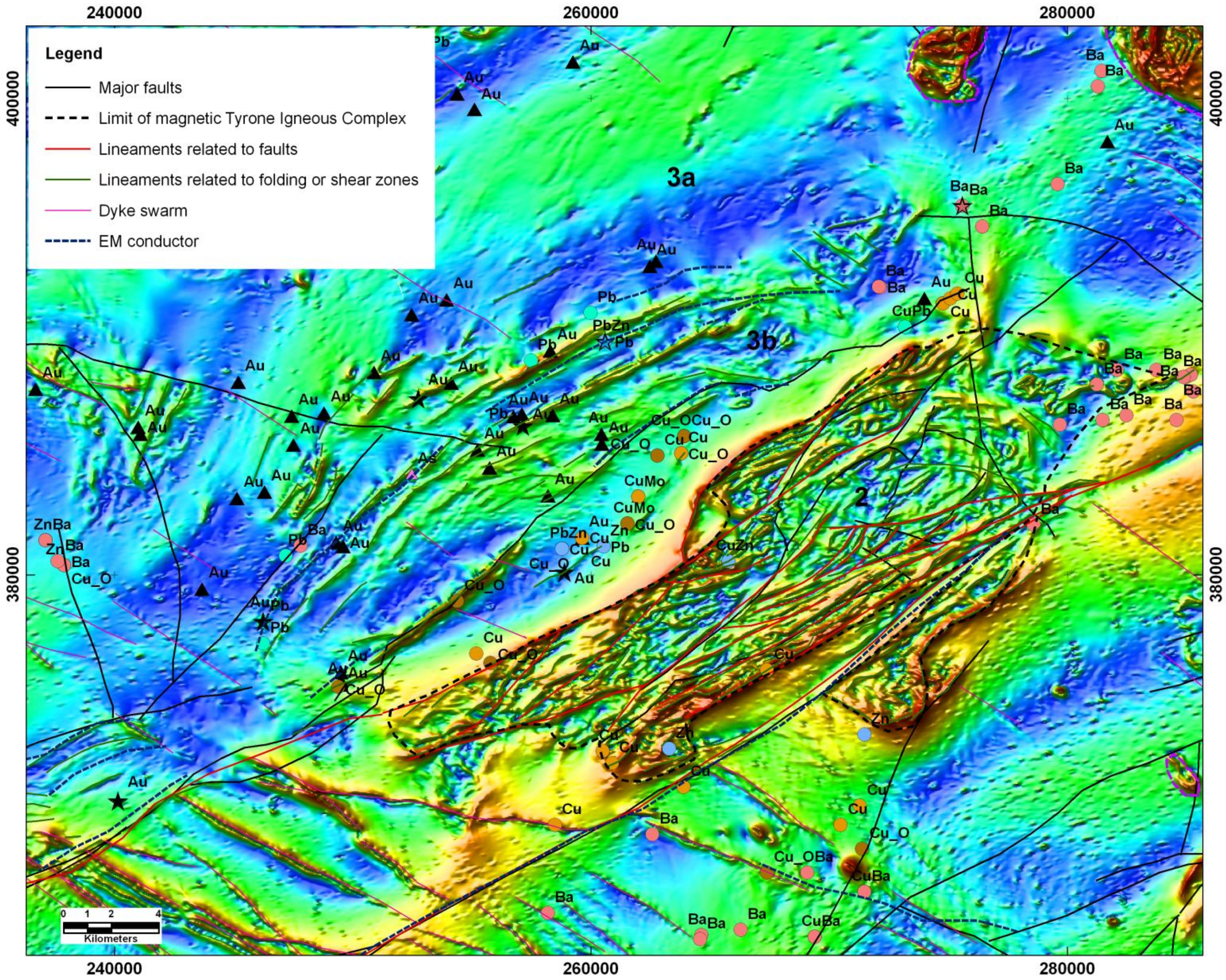

Figure 22 Magnetic pseudogravity horizontal gradient anomaly map of the Tyrone Igneous Complex and Dalradian rocks of County Tyrone with reported mineral localities. Significant mineral deposits are shown as stars, gold and other precious minerals as triangles and base metals as colour coded circles. Colour shaded relief image illuminated from the north west.

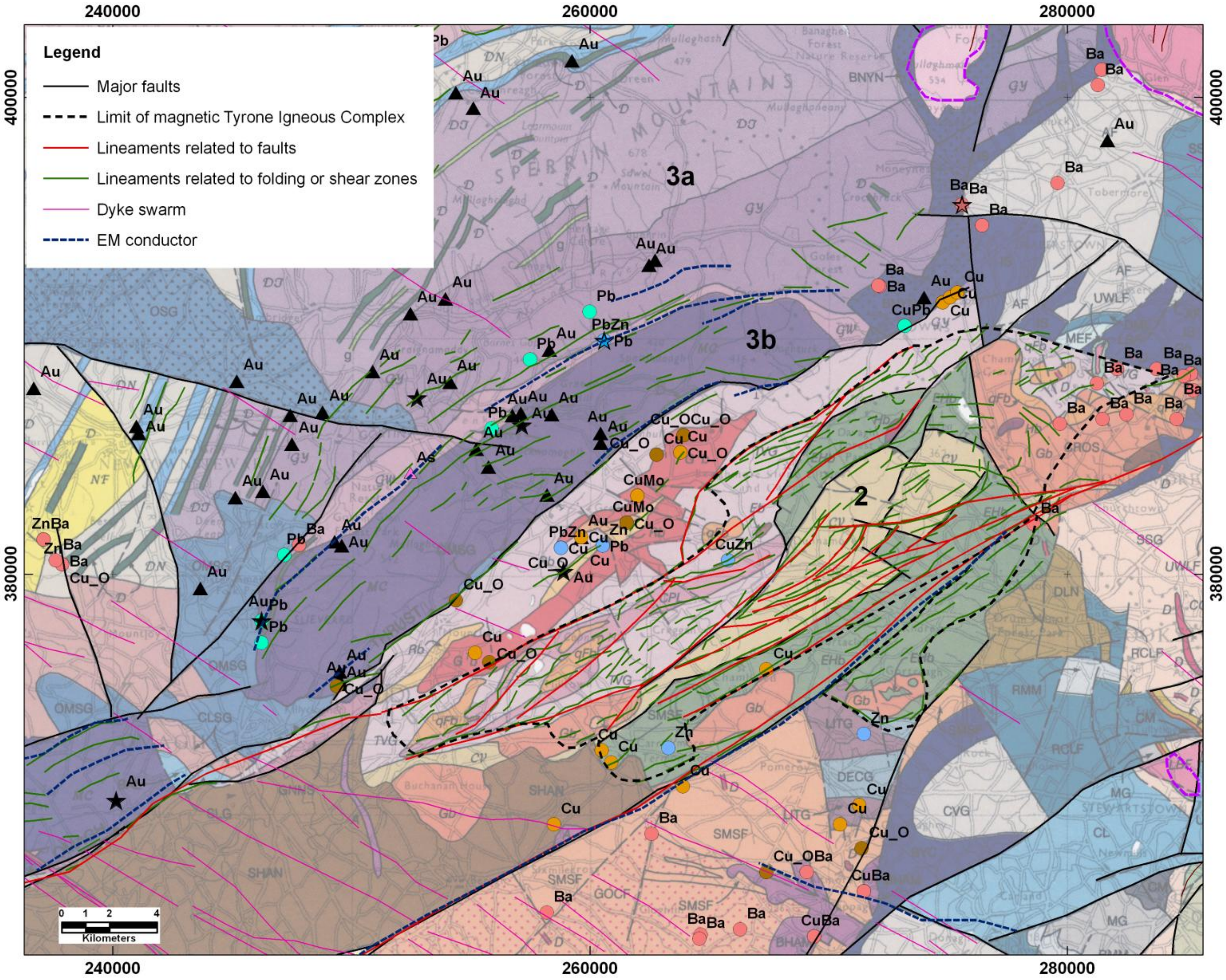

Figure 23 Structural interpretation map of the Tyrone Igneous Complex and Dalradian rocks of County Tyrone with reported mineral localities. Significant mineral deposits are shown as stars, gold and other precious minerals as triangles and base metals as colour coded circles. Colour shaded relief image illuminated from the north west.